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DESIGN *and* CONTROL
of
CONCRETE MIXTURES

Engineering

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PORTLAND CEMENT ASSOCIATION

Concrete for Permanence

FOREWORD

THE three fundamental considerations which should determine the design of concrete structures are strength, durability and economy. Strength and economy have long been considered the determining elements. These should not, however, be allowed to obscure the equally important requirement of durability. Too much emphasis on the element of economy in construction may lead to methods and practices not suitable to the production of concrete of proper resistance to the elements.

Fortunately, the factors which govern the strength of concrete affect with equal importance the resistance to percolation of water and to weathering. Once this fact is pointed out, the vast experimental data on the strength of concrete are made available for use in the solution of the problems of making permanent structures.

This booklet is a revision of an earlier publication carrying the same title, but which was concerned solely with the design of concrete mixtures. While the major part of the present booklet is, of necessity, devoted to the same subject, its scope has been broadened to include a general treatment of the factors essential to the economic production of concrete of proper strength and durability. Particular emphasis is placed on the selection of materials, the mixing and placing of concrete, and protection during curing, also upon the importance of proper workability in the design of the mixture.

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L. ALLEN

DESIGN AND CONTROL OF CONCRETE MIXTURES

CONCRETE is a mixture of cement, water and inert materials, put in place in a plastic condition, but hardening soon after, due to the process known as the hydration of the cement. Unlike most other materials, because it is placed in this plastic condition, concrete cannot be tested for quality at the time it is fabricated. This imposes severe restrictions on the making and placing, for unless each of these is carefully carried out, together with the subsequent curing, the finished product may not meet the requirements of the work.

The fundamental requirements of practically all concrete are strength, durability and economy. These can be obtained only by the proper selection of the materials, an intelligent design of the mixture and the adoption of proper methods of mixing and placing the concrete and protection during the curing period. The effect of each of these factors has been definitely determined by extensive research, the results of which make it practicable to design mixtures so that the properties of the concrete can be predicted at the time of fabrication with considerable accuracy. The outstanding feature of these investigations was the discovery of the dependence of the strength and other qualities of concrete upon the quantity of the mixing water. While the importance of proper control of the mixing water has long been recognized, it was only through these later researches that the relation between strength and water-cement ratio has been definitely established and fully confirmed as a law.

WATER-CEMENT RATIO STRENGTH LAW

THE water-cement ratio strength law can be stated as follows:

For given materials and conditions of manipulation, the strength of concrete is determined solely by the ratio of the volume of mixing water to the volume of cement so long as the mixture is plastic and workable.

In other words, if one cubic foot of water is used for each cubic foot of cement in a concrete mixture, the strength at a given age is fixed, regardless of what quantities of aggregates are used, so long as the mixture is plastic and workable and the aggregates are clean and made up of sound particles. The significance of this important conclusion is more readily appreciated when the cement paste is thought of as a glue binding the aggregates together. The addition of excess mixing water serves only to dilute the glue and reduce the strength. **Designing a concrete mix for a given strength, therefore, consists in selecting the water-cement ratio corresponding to that strength and finding the most suitable combination of aggregates which will give the desired workability when mixed with cement and water in this ratio.**

The water-cement ratio strength law can be represented by a curve, as in Fig. 1. In this Fig., curve "A" represents the results of thousands of tests made at the Structural Materials Research Laboratory. Many subsequent investigations at this laboratory and at other laboratories have shown practically the same relation between the compressive strength at 28 days and the water-cement ratio. At the same time other tests have given similar curves, in some cases higher and in other cases lower than curve "A." The differences in results from different tests are due largely to differences in materials, conditions of manipulation and curing.

EFFECT OF WATER-CEMENT RATIO ON OTHER QUALITIES

THE water-cement ratio not only governs the compressive strength of concrete, but, likewise, other desirable qualities. Flexural strength, resistance to wear, modulus of elasticity and the bond between concrete and reinforcement all bear definite relations to both the compressive strength and the water-cement ratio.

The resistance of concrete to the severe conditions of weathering and to the action of sulphate waters is determined largely by the degree of impermeability. Impermeable concrete requires non-porous aggregates thoroughly incorporated in a cement paste that is itself impermeable. An impermeable paste requires in turn a low water-cement ratio; the thorough incorporation of aggregates necessitates a plastic, puddleable mix. Thus proper control of the mixing water is the vital factor in the production of durable concrete.

SELECTION OF WATER-CEMENT RATIO FOR DESIGN OF THE MIX

The selection of a water-cement ratio as the basis for designing a concrete mixture involves a consideration of both the strength requirements and the degree of exposure to which the concrete is to be subjected. The classification given in Table I shows the recommended quantities of mixing water per sack of cement for a number of types of structures, with reference to their exposure. The types of structures given in each group are suggestive; the exact classification in individual cases or of other types will depend upon the conditions of exposure at the particular site. This classification is based on the conditions prevailing in the greater part of Northern United States and assumes proper workability of the mixture, thorough mixing, placing the concrete by puddling to completely fill the form and incorporate the reinforcement and thorough protection from drying out or freezing during the early hardening period.

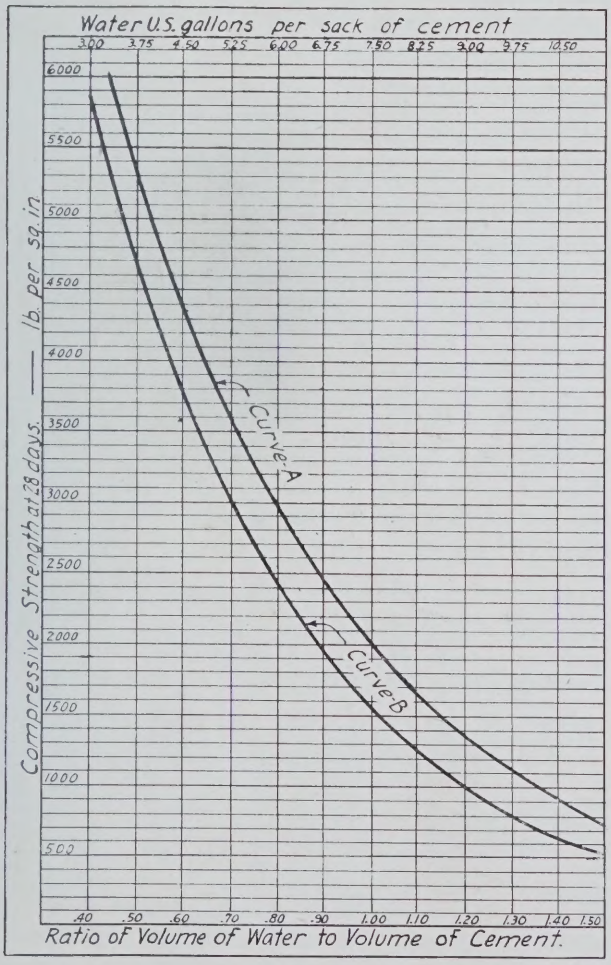

Fig. 1

Effect of quantity of mixing water on the strength of concrete. Curves based on average values from nine series of tests made over a period of four years. Curve A to be used for design where the water-cement ratio is carefully controlled by accurate measurement of quantities of water, cement and aggregate, with proper correction for water carried by the aggregate. Curve B to be used for design where the water-cement ratio is indifferently controlled and where only rough methods are used for measuring quantities of materials.

In many cases the strength requirements may call for a higher class of concrete and hence a lower water-cement ratio than would be required for the degree of exposure. The strengths indicated in the first column of Table I are based on curve "A" of Fig. 1, which represents the results of many tests on a wide variety of materials and mixtures. This curve is recommended for use with average materials where the construction operations are carefully controlled, especially the water-cement ratio.

It should not be expected that the relation between the water-cement ratio and the compressive strength will be exactly the same on all jobs as changes in this relation are caused by differences in materials and methods of manipulation. It is desirable, therefore, to have tests made for each job, including several water-cement ratios and using the materials selected for the work. From these tests a "job curve" representing the strength under the actual conditions on the particular project can be plotted and the water-cement ratio required to produce concrete of the desired strength can be taken directly from this curve. When this method is used care should be taken to make enough tests to give representative values. In advance of more specific data the water-cement

TABLE I

CLASSES OF CONCRETE FOR DIFFERENT DEGREES OF EXPOSURE

Class of Concrete (Expected Strength at 28 days lb. per sq. in.)	Maximum Quantity* Mixing Water U. S. gal. per sack of cement (94 lb.)	Type of Structure or Degree of Exposure
3000	6	Roadways, piles, pressure pipe and tanks. Thin structural members in severe exposure. Walls, dams, piers, etc., where exposed to severe action of water and frost.
2500	6¾	Sewers, bridges, walls, dams, piers, etc., for all weather conditions and moderate action of water and frost.
2000	7½	Ordinary enclosed reinforced concrete buildings. Bridges and retaining walls of heavy sections in moderate exposure.
1500	8¼	Mass concrete, basement walls, etc., protected from water or severe weather conditions.

* Free water or moisture carried by the aggregates must be included as part of mixing water.

ratios of Table I can be considered as fully meeting the requirements of exposure, where proper methods of placing are followed.

Curve "B" in Fig. 1 gives values about 500 lb. per sq. in. lower than curve "A" and represents average values that should be obtained on the small job or where the conditions or equipment are such that the net quantity of water entering the mix cannot be accurately controlled. The water-cement ratio to be used as the basis for the design of the mix can be taken from either of these curves, depending upon the accuracy with which the job will be controlled.

OTHER FACTORS AFFECTING STRENGTH OF CONCRETE

In the water-cement ratio law it is stated that the strength of concrete is determined by the water-cement ratio for given conditions of manipulation. Because of the importance of the effect of manipulation some standard procedure of mixing, placing and curing the concrete must be used in a comparison of strength between different mixes, since the time of mixing and the conditions under which the concrete is cured affect the strength. The strength also changes with the age. A brief summary of the effect of each of these factors will be given as of assistance in the application of the water-cement ratio law.

Time of Mixing

Tests show that the strength of concrete is increased by longer periods of mixing. Typical values from these tests are shown in Fig. 2. The rapid increase in strength for different periods of mixing up

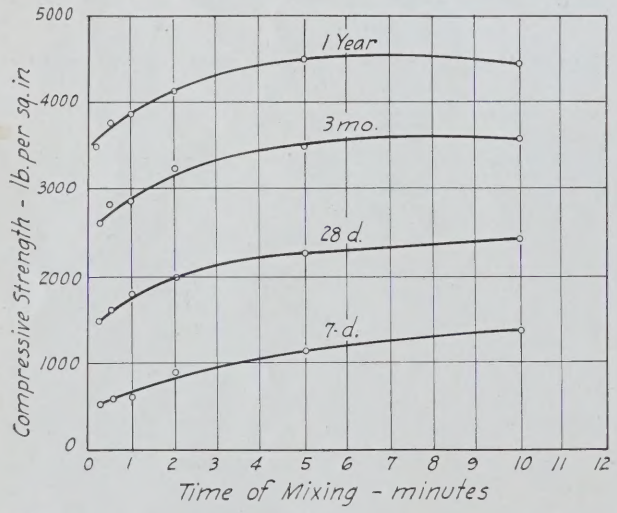

Fig. 2
Typical relation between time of mixing and the compressive strength of concrete.

to about two minutes can be seen on this curve. For instance, concrete of the usual quality mixed for that period is from 20 to 35 per cent, that is, from 500 to 700 lb. per sq. in., stronger than concrete mixed only 15 seconds.

In the tests from which these curves were constructed it was found that thorough mixing also makes for more uniform concrete. Specimens made of concrete mixed for only 15 seconds showed an average variation of individual specimens of about 30 per cent from the average strength, while specimens made of concrete mixed for two minutes varied less than 10 per cent. Furthermore, thorough mixing gives increased workability, which in turn requires less labor in placing and, therefore, permits the use of larger quantities of aggregate with a given quantity of cement and water in their fixed ratio. A still further advantage of thorough mixing is that it is of great assistance in securing the homogeneity necessary for water-tight concrete.

Small changes in the speed of the mixer have little effect on the strength of concrete. The tests indicate that it is largely the time element of mixing and not the rate of rotation of the mixer that influences the strength and quality. If increased output is needed, it should be obtained by a larger mixer or a second mixer rather than by speeding up the mixer. Mixing concrete for one to two minutes, depending upon the requirements of the job, after all materials, including water, are in the mixer is a good requirement.

Effect of Curing Condition

Concrete hardens because of chemical reactions between portland cement and water. The process is

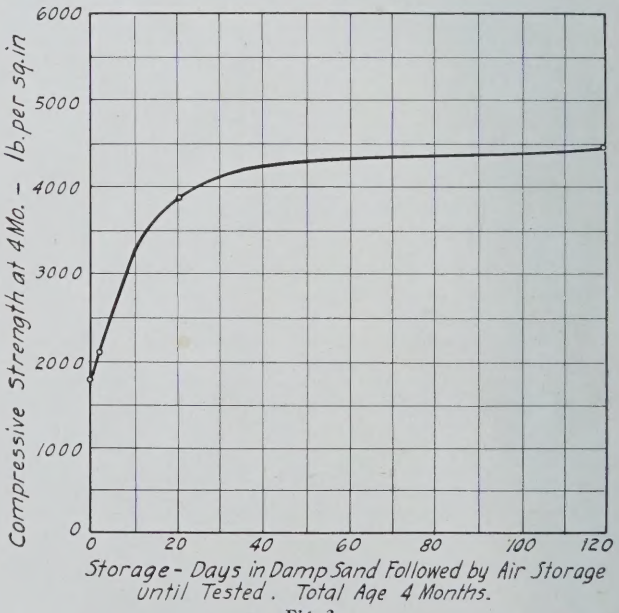
Compressive Strength at 4 Mo. - lb. per sq. in.
6000
5000
4000
3000
2000
1000
0
0 20 40 60 80 100 120
Storage - Days in Damp Sand Followed by Air Storage until Tested. Total Age 4 Months.

Fig. 3
Typical relation between curing condition and the compressive strength of concrete. Specimens were cured in damp sand for the period indicated in horizontal scale, followed by air storage until time of test. All tests made at four months.

slow but continues indefinitely so long as temperatures are favorable and moisture is present to complete the hydration. The concrete should be kept damp, if possible, for from seven to ten days for ordinary construction and in some special cases for even longer periods. When the concrete is allowed to dry out too soon only part of its potential strength is attained. Fig. 3 gives a summary of the results of tests, showing that moist curing during the early hardening period greatly increases the strength. In this series of tests all the specimens were tested at the age of four months but they were cured in damp sand for various periods and then allowed to cure in dry air until tested. It will be seen from Fig. 3 that an increase in strength of 75 per cent was obtained by keeping the concrete damp the first ten days instead of letting it dry out. Keeping the concrete damp three weeks increased the strength 115 per cent and for four months 145 per cent over the strength of concrete cured the entire period in a dry atmosphere.

Proper curing is one of the most important elements in the production of water-tight concrete. Building up the internal structure of the concrete through more complete hydration is one of the most effective and economical means of making it impervious to water.

The resistance to abrasive action is increased in a similar manner, the tests showing the importance of properly curing floors, pavements and other surfaces subject to such wear. Continuous damp curing, *particularly in the early stages of hardening*, aids in securing a hard, dense surface and in preventing checking and dusting.

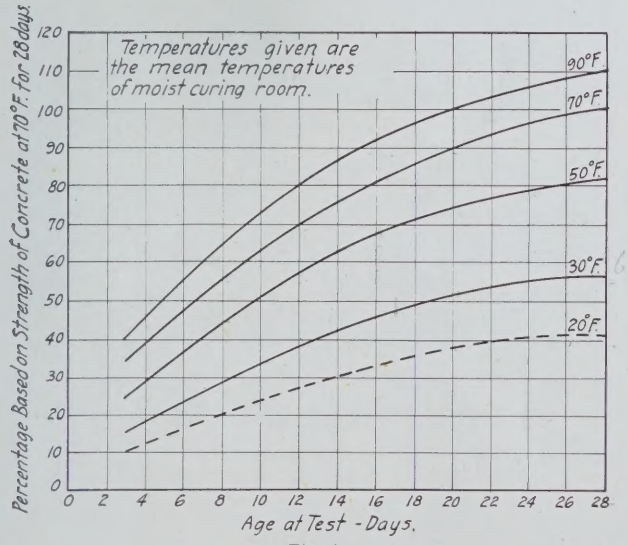

Fig. 4

Effect of temperature during curing period on the compressive strength of concrete. Data taken from Bulletin No. 81, Engineering Experiment Station, University of Illinois.

The rate at which the hardening of concrete proceeds is affected by the temperature. This is brought out very clearly by tests made at the University of Illinois and illustrated in Fig. 4. It will be seen from this chart that concrete allowed to harden at a temperature near freezing for 28 days will have a strength of only 60 per cent of that shown by concrete cured in a temperature of 70 degrees Fahrenheit.

These considerations show the importance of proper curing in developing the strength of concrete or its resistance to weathering. It is of no less importance in the matter of storage of test specimens if uniform and dependable results are to be obtained. The standard method for curing concrete specimens of the American Society for Testing Materials requires temperatures between 60 and 75 degrees F. and curing either in damp sand or a moist room. All tests made by the Structural Materials Research Laboratory* described in this booklet were made in accordance with this standard method.

Effect of Age

As stated previously, the chemical process of hardening of the concrete continues indefinitely so long as moisture is present and the temperature is favorable. The strength of the concrete, therefore, under these conditions, increases with age. This increase is very rapid in the early ages but continues more slowly for an indefinite period. Tests that have been made at various ages up to five years on concrete cured in a moist atmosphere show increasing strength. These tests are illustrated in Fig. 5, which shows that for damp curing the increase in strength is proportional to the logarithm of the age. The strength of concrete at 28 days is now commonly taken as a standard for comparison and the design data in this booklet are based on that standard.

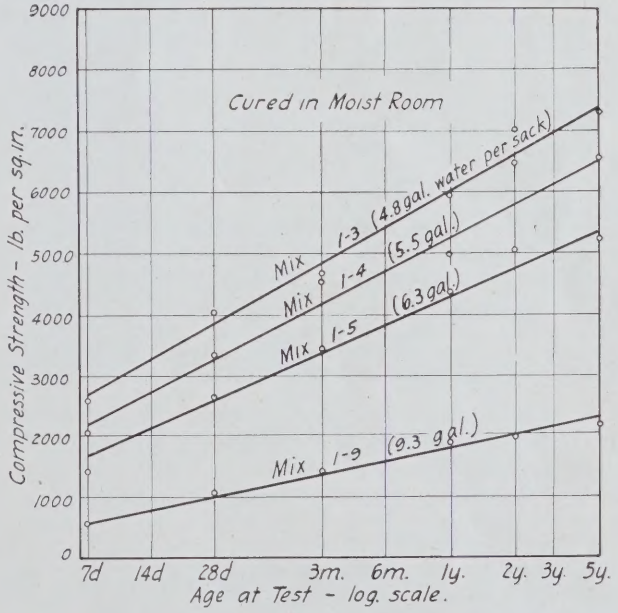
Cured in Moist Room
Mix 1-3 (4.8 gal. water per sack)
Mix 1-4 (5.5 gal.)
Mix 1-5 (6.3 gal.)
Mix 1-9 (9.3 gal.)
Compressive Strength - lb. per sq. in.
Age at Test - log. scale.

Fig. 5
Increase in strength of concrete with age. Moist curing.

* **Experimental studies of concrete and concrete materials formerly carried out by the Structural Materials Research Laboratory through the cooperation of the Lewis Institute and the Portland Cement Association are now being continued at the new Research Laboratory of the Portland Cement Association.**

The ultimate possible strength attainable by concrete is contingent on conditions at the time of placing; that is, the nature of the materials, time of mixing and especially the water-cement ratio. Thus, these factors affecting the strength at the early ages have the same influence throughout the life of the concrete.

SELECTION OF MATERIALS

Cement

Portland cement should conform to the Standard Specifications and Tests for Portland Cement (Serial Designation: C9-26) of the American Society for Testing Materials.

Water

The water should be suitable for drinking unless it is known by test or experience that other waters are satisfactory. Sea water should not be used for mixing concrete on account of the danger of corrosion of steel reinforcement.

Aggregates

All aggregates should consist of inert materials that are clean, hard, strong and durable. The particles should not be coated with clay or dirt. Weak, friable or laminated materials are undesirable. Shale and stones laminated with shale are especially to be avoided. A visual inspection will usually disclose any weakness in the aggregate. If any doubt exists the aggregate may be tested in concrete specimens. For exposed structures, where durability is important, only aggregates of proven resistance to the particular type of exposure should be used. A good specification for aggregates is that they meet the requirements of the "Tentative Specifications for Concrete Aggregates" of the American Society for Testing Materials given on page 25. The size and grading of the aggregates are important from the standpoint of economy, as they have a very decided effect on the workability of the concrete and the amount that can be produced from a unit volume of cement when used with a fixed proportion of water.

The suitability of aggregates from the standpoint of cleanness may be determined by following the standard methods of the American Society for Testing Materials. These tests are the "Colorimetric Test for Sands" for the determination of organic impurities described on page 27 and the "Standard Method of Test for Quantity of Clay and Silt" described on page 27. The "Sedimentation Test" given on page 31 may be used in the field as an approximate determination of the clay or silt content. In all such tests it is, of course, important that the samples of aggregates are representative of the materials as used on the job. The standard method of sampling aggregates described on page 25 should therefore be followed.

Fig. 6

Quartering aggregate sample. See standard method of sampling aggregates.

THE DESIGN OF CONCRETE MIXTURES

As stated on page 4, designing a concrete mix for a given strength or condition of exposure consists in selecting the water-cement ratio corresponding to those requirements and finding the most suitable combination of aggregates which will give the desired workability when mixed with cement and water in this ratio. In determining the proportions of the materials it is desirable to use those proportions which will give most economically the necessary workability. The most economical concrete does not always result from the mix having the lowest cement factor, nor the mix with the lowest cost for materials, but rather from that mix for which the total cost—materials, handling and placing—is the lowest. The design of a mixture, then, involves considerations of workability and placing as well as grading of the aggregate and the proportions of materials.

There are two methods of designing concrete mixtures, using the water-cement ratio law as a basis. In one method, which may be designated as the

calculation method, the grading of the aggregates is determined by test and use is made of charts and tables based on extensive laboratory investigations. The other method is known as the trial method, in which trial batches of concrete are made, using the required water-cement ratio and varying the aggregate proportions until the desired workability is obtained. **The objective of either method is to obtain a mix that is workable, using the correct ratio of water and cement.**

Factors in the Design

As pointed out above, the most economical concrete is not necessarily the one with the lowest quantity of cement. It is true, however, that the most important single factor in the cost is the quantity of aggregate that it is practicable to use with a given quantity of cement. The other factors are the relative cost of cement and aggregate and the cost of transporting and placing the concrete. With cement and water in a fixed ratio, the use of a stiffer mix permits more aggregates to be crowded into the cement paste and thus gives a larger volume of concrete. The workability necessary will be determined by the conditions of the job.

In many instances it will be found practicable to use somewhat stiffer mixtures than has been the practice in the past without adding materially to the cost of handling or placing. This should not be taken as an endorsement of the dry mixes sometimes advocated. Too much emphasis cannot be placed upon the necessity for a mix that can be readily puddled into place. With the water-cement ratio fixed it is just as important to avoid mixes too stiff to place properly as it is to avoid those that are over wet with their train of evils—porosity, segregation and laitance.

Fig. 7
Rodding concrete for slump test.

Factors Affecting Workability

When the quantity of water for each sack of cement is fixed, workability will be found to be of even more vital concern to the contractor than under the method of fixing the aggregate proportions and allowing the water to be adjusted to give the necessary fluidity. A certain amount of fluidity will always be required, but when it is discovered that this can be obtained only through the use of more cement a new basis of judging the value of workability will be established. With some latitude open to the contractor in the matter of workability and proportions he will be quick to select those mixes which give him the necessary workability at the lowest cost.

For most materials and the usual range of prices it will be found that lowest cost will result from those mixes that are neither too harsh for proper placing nor too high in fine aggregate for proper density. Increasing the coarse aggregate beyond a certain point makes only slight reduction in the cement

Fig. 8
Measuring the slump.

factor, while the cost of placing increases rapidly. Reducing the coarse aggregate makes for smoother working mixes, but with a fixed water-cement ratio a point is rapidly reached where the increased water requirements for the fine aggregate raises the cement factor beyond all economical considerations. These factors fix within rather narrow limits the range of proportions which can be used with economy.

Because of the restriction thus naturally imposed by limiting the amount of water for each sack of cement, experienced concrete foremen can generally be depended upon to obtain a proper balance between the various factors, with the result that the

concrete will be neither harsh nor honeycombed on the one hand nor porous and over wet on the other. About the only condition likely to arise in which the good judgment of the experienced concrete man might not be sufficient is the case where high water-cement ratios (that is, lean mixtures) are to be used and the materials available are extremely coarse. In this case separation of the wet cement paste from the aggregates cannot be corrected by any change in the proportion of coarse to fine within the limits recommended in a succeeding paragraph (Table III) or by any change in the total amount of aggregate in the mix. The only remedy lies in reducing the water-cement ratio, thus supplying through the richer mixes the necessary fines. This is only another way of saying that certain aggregates cannot be used to make workable concrete that will not segregate except in rich mixes.

A measure of the consistency that may be used is the slump test described on page 28. This test is not an absolute measure of workability and it should not be used to compare mixes of wholly different proportions or of different kinds of aggregates. Under conditions of uniform operations, however, the slump is useful in indicating a change in the character of the materials, the proportions or the water content. To avoid mixes too stiff or too wet, concrete which shows a slump falling within the limits given in Table II below is recommended.

TABLE II

RECOMMENDED SLUMPS FOR CONCRETE

Type of Structure	Slump—inches Minimum	Maximum
Massive sections, pavements and floors laid on the ground	1	4
Heavy walls, slabs, beams	3	7
Thin walls, columns, etc.	4	8

The grading of the aggregate is important on account of the effect of this factor on the workability and the yield of concrete. With fixed proportions of cement and water and with a given condition of workability, as measured by the slump, a greater volume of aggregates can be used when coarsely graded than when small sizes predominate. This fact may account for a tendency in some cases to use mixtures that are undersanded and which result in concrete that is rather harsh. Too harsh a mixture will result in honeycombing in the finished work. A slight excess of sand or fine material over that strictly required for maximum yield will give a smoother, more workable mix and smoother surfaces. Too much fine material on the other hand will produce porous concrete of low density and must be guarded against. If the proportions of coarse and fine aggregates are kept within the limits given in Table III, satisfactory density will usually be obtained for water-cement ratios of 7½ gallons or less per sack of cement with plastic and workable mixes.

TABLE III

RECOMMENDED PROPORTIONS OF AGGREGATES

Maximum size of coarse aggregate Inches	Ratio of coarse to fine on basis of dry compact volumes Minimum	Maximum
⅜	0.40	0.80
¾	0.60	1.50
1 and over	1.00	2.00

Importance of Good Aggregates

While the development of the water-cement ratio strength law has made it possible to obtain good concrete from aggregates previously held to be unsatisfactory (largely on account of grading) it should not be assumed that care in the selection of materials is unimportant. Dirty aggregates, for example, may lead to failure even with proper water control if the dirt is of the kind to prevent hardening of the cement or to lead to disintegration. Even if the extraneous material does not lead to failure, its presence may greatly increase the cost, because it requires more water for workability, which, with a fixed water-cement ratio, means a richer mix.

Uniformity of the aggregates as received on the work, that is, as to grading and moisture content, will be found economical, especially on large jobs. On small jobs, where the proportions or water content can be adjusted from time to time, as may be necessary to maintain uniformity in the consistency, some variation in materials received may be permitted.

DESIGN OF MIXTURES BY THE TRIAL METHOD

(*For Design by Calculation Method see page 17*)

The design of mixtures by the trial method consists in finding directly by means of trial batches the combinations of aggregates which will give most economically the desired workability when used with cement and water in the ratio selected as necessary to meet the strength requirements or condition of exposure. The procedure to follow will depend upon the facilities at hand and the number of aggregates which are available for the particular piece of work.

If only one fine and one coarse aggregate are available, the necessary trials can be most readily made on the work, probably in full-sized batches. For this purpose the moisture content of the aggregates must first be determined. This can be done by drying a

representative sample, weighing the material before and after drying. For the first batch arbitrary quantities of fine and coarse aggregate can be used based on previous experience or an estimate of the probable requirements for the particular work. In computing the water to be added to this batch, the amount carried by the aggregates, as shown from the moisture test, is deducted from the total amount indicated by the water-cement ratio selected. A glance into the mixer will show whether the estimated quantities are giving a consistency near enough to that desired to permit its use directly in the work. If this is not the case, the proper additions can be made before completing or discharging the mix. If the mix is too stiff, both cement and water in the proper ratio should be added. If it is too wet, either sand or coarse aggregate or both can be added as appears desirable. The moisture carried by these small additions will, of course, slightly alter the water-cement ratio but, if the additions are small, this change would be slight and could be ignored, providing in subsequent batches the correct ratios are maintained.

The appearance of this first batch and the ease or difficulty with which it is puddled into the forms will determine what changes should be made in the second batch. The most important questions to settle are the relative amounts of the fine and coarse materials and the total amount of aggregate to use with each sack of cement. Since the quantities used in charging the mixer are known, it will be a simple matter to compute the cost of the finished concrete for the various batches if the skip into which the mixer discharges is calibrated to indicate the volume of concrete produced. After several trial batches, using varying proportions of coarse and fine, the most desirable mix can be determined from a consideration of the cost per cubic yard and the degree of workability obtained.

The essential factors in such a series of trials are that the selected water-cement ratio be accurately maintained and that the resulting mixtures are really workable. The experienced concrete man should have no difficulty in selecting the combination most suited to the work at hand, as the requirements of placing almost invariably prevent the use of mixtures that are too harsh. The less experienced man may, in his desire to obtain the greatest possible yield, use a larger proportion of coarse aggregate than is desirable for ease of placing and freedom from honeycombing. This condition should of course be guarded against.

Where a number of aggregates are available, and it is desired to study their relative advantages, a procedure exactly similar to that outlined above can be followed either on the work or in the laboratory. For preliminary studies small batches (¼ to ½ cu. ft.) mixed by hand will be found convenient to use and of sufficient size to give reliable measurements and indications as to workability. It is desirable for these tests to spread the aggregates out for a period before using, so that all surface moisture is evaporated, leaving only the water absorbed by the particles. This eliminates the necessity for correcting either for free water in the aggregates or for absorption. Dry aggregates may be wetted and surface dried to bring them into this condition. It may sometimes be found convenient to use fully dried materials, adjusting the quantity of water for each batch to allow for the absorption which may take place in the aggregate during the period of mixing and handling. For this purpose the absorption during a period of 30 minutes can be used. This can be found by absorption tests made in accordance with the Recommended Practice of the American Society for Testing Materials (1920 Proceedings Part 1, Appendix 2, of Report of Committee C-9). In the absence of tests average quantities given below may be used as a basis:

Approximate Absorption of Aggregates

Average sand	1.0 per cent by weight
Pebbles and crushed limestone	1.0 per cent by weight
Trap rock and granite	0.5 per cent by weight
Porous sandstone	7.0 per cent by weight

Very light and porous aggregate may be as high as 25 per cent by weight.

Where curve "B" of Fig. 1 is used as the basis of design it will usually be sufficiently accurate to base the corrections for moisture on approximate values as follows:

Approximate Quantity of Free Water Carried by Average Aggregates

Condition of Aggregate*	Approximate Quantity of Free Water
Very wet sand	¾ to 1 gal. per cu. ft.
Moderately wet sand	about ½ gal. per cu. ft.
Moist sand	about ¼ gal. per cu. ft.
Moist gravel or crushed rock	about ¼ gal. per cu. ft.

* The coarser the aggregate, the less free water it will carry.

Quantities of Materials

The quantities of materials in a concrete mixture may be accurately determined from the fact that the volume of concrete produced by any combination of materials, so long as the concrete is plastic, is equal to the absolute volume of the cement plus the absolute volume of the aggregate plus the volume of water. The absolute volume of a loose material is the actual total volume of solid matter in all the particles. This can be computed from the weight per unit volume and the specific gravity as follows:

$$\text{Absolute Vol.} = \frac{\text{unit weight}}{\text{specific gravity} \times \text{unit wt. of water.}}$$

The method can best be illustrated by an example. Suppose the concrete consists of 1 sack of cement (94 lb.), 2.2 cu. ft. of fine aggregate weighing 110 lb. per cu. ft., and 3.6 cu. ft. of coarse aggregate weighing 100 lb. per cu. ft. and is to be mixed with a water-cement ratio of 7 gal. per sack. The specific gravity of the cement is usually about 3.1 and of the more common aggregates about 2.65. The volume of con-

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crete produced by the above mix is calculated as follows:

$$\text{Cement} = \frac{94}{3.1 \times 62.5} = .49 \text{ cu. ft.}$$

$$\text{Fine Aggregate} = \frac{110 \times 2.2}{2.65 \times 62.5} = 1.46 \text{ cu. ft.}$$

$$\text{Coarse Aggregate} = \frac{100 \times 3.6}{2.65 \times 62.5} = 2.18 \text{ cu. ft.}$$

$$\text{Volume of Water} = \frac{7.0}{7.5} = .93 \text{ cu. ft.}$$

Total Volume of Concrete produced = 5.06 cu. ft.

Thus 1 sack of cement produces 5.06 cu. ft., neglecting absorption or loss of water in manipulation. The cement required for one cubic yard of concrete is, therefore, $\frac{27}{5.06} = 5.34$ sacks or 1.33 barrels. The quantities of sand and stone required can be found from a simple computation based on the number of cubic feet used with each sack of cement; thus, for the sand, $\frac{5.34 \times 2.2}{27} = .43$ cu. yd. required, and for the stone, $\frac{5.34 \times 3.6}{27} = .71$ cu. yd. of stone.

For unusual materials such as blast furnace slag, special light weight aggregates, etc., the exact specific gravities should be used. It will be found that, for the purpose of estimating quantities, the average value —2.65, given previously, will be sufficiently accurate for sand and gravel and the common varieties of crushed rock.

CONTROL OF CONCRETE IN THE FIELD

Once a satisfactory and economical mixture for the required water-cement ratio has been obtained there remains the problem of producing this mixture on the work in such a manner that there is delivered to the place of deposit a continuous supply of concrete, each batch of which is as nearly like the other batches as it is possible to be. Uniformity in this sense refers not only to water-cement ratio and, therefore, strength but to consistency as well. Nothing quite so disorganizes the work of placing concrete as to have the consistency vary continually from one extreme to the other. The essential factors in the proper control of the quality of concrete in the field may be, therefore, summarized under the following requirements:

Uniform supply of aggregates
Proper design of mix
Adequate measuring and mixing equipment
Suitable means of transportation
Proper care in placing
Adequate curing
Follow-up tests to determine quality

Selection of Aggregates

In the selection of aggregates it is not only important to consider the requirements as to strength, durability and economy but also to consider the source of supply with respect to capacity for delivering uniform materials from day to day.

Aggregates should be purchased under a definite specification which should be rigid enough to meet fully the requirements of the work but containing no unnecessary restrictions which will increase the cost or restrict the supply. The specifications should cover the quality and cleanness with definite limits and tolerances. Tests should be made either as the material is loaded at the producing plant or as delivered on the work.

Since grading is largely a matter of economy, too great restrictions in this respect are undesirable in the general specification except clauses to insure uniformity. The contractor should have some leeway in the selection of materials but once the selection has been made the variation in grading should be limited. His specification for purchasing aggregates may be based on samples of the selected materials with permissible variations and tolerances.

The tests for cleanness and grading of the aggregates are described herein. Structural soundness as a general quality can usually be determined by visual inspection. The frequency of making tests will depend upon the uniformity of the aggregates. At the beginning of operations it may be advisable to make these tests several times a day, while as the work progresses it may be necessary to make tests only once a week.

Uniformity in moisture content if it were possible would greatly simplify control at the mixer. While it is too much to hope for uniformity under all conditions, under certain conditions it might be quite feasible to obtain uniformity during a limited period, for example, a single day's operation. Where such uniformity could be secured, the control of the moisture would be greatly simplified, for adjustments in measuring devices would be required only at infrequent intervals, thus permitting a continuous operation without change in consistency over a considerable period of time.

Design of Mix

The design of the mix is discussed in other sections of this bulletin and needs emphasis here only to point out the importance of the workability of the mix on the problem of transporting and placing. The mix should be designed so as to avoid segregation in transporting or placing and to permit puddling

without excessive spading or the accumulation of water or laitance on the surface.

Measuring and Mixing Equipment

Selection of equipment must, of course, depend primarily upon the type and extent of the work and no general recommendations can be made regarding it. The more extensive the work and the more severe the requirements as to uniformity, the more important becomes the layout and equipment. On many jobs, if full advantage is taken of the possibilities of properly designed mixes, it would no doubt be found economical to install carefully designed equipment. Batcher plants are now very common and the inundation method of measuring the sand and water is being used quite extensively. Equipment for weighing all of the ingredients is also coming into use on a considerable scale. In many cases their use has been justified even under the older practice of specifying concrete solely on the basis of arbitrary mixes. When the newer practice of designing concrete mixtures for a given requirement comes into more general use, such plant installations will be quite common.

Of greatest importance is the proper control of the mixing water. The whole intent and purpose of designing a mixture by the water-cement ratio strength law will be lost if the necessary precautions are not taken to maintain, throughout the duration of a job, the accurate measurement of the water. Corrections for the moisture content of the aggregates must be made at the proper times. During varying weather conditions or when stock piles have been subjected to rains or to rapid drying out the tests should be more frequent. Many concrete mixers are now equipped with water-measuring devices. Such devices should not permit the leakage of water into the mixer before or after the tank has been discharged. The tank should be calibrated to give accurate quantities, and adjustments should be made only by the man designated by the engineer.

Mixing equipment should be selected to give the required output without curtailing in any way the time of mixing. For concrete where waterproof construction is an essential or where the structure is to be exposed to severe weather conditions a period of mixing somewhat greater than the customary one minute will be found to be economical. In many lines of work if the test of quality of the finished product is introduced it will likely be found that one of the economical methods of producing the desired quality will be through longer time of mixing.

Transporting Concrete

As in the case of measuring equipment, selection of means of transporting from the mixer to place of deposit is primarily a question of economy, the only qualification being that the means selected must not interfere with the delivery at the place of deposit of concrete of the proper quality. The design of the mix may be governed largely by the type of equipment to be used in transporting concrete. If chuting equipment is to be used the slope and length of the chute may be adjusted to permit the movement of the desired mix or the mix may be adjusted to fit the slope of the chute. The extra cement required to maintain quality with the increased flowability may easily be justified by the saving in transportation costs.

Even with transportation in buggies or wheelbarrows some consideration must be given to the mixture in order that segregation does not take place in handling over the rough runways. Central mixing plants with long distance haul either in trucks or cars likewise impose certain restrictions.

Care in Placing

No element in the entire cycle of concrete production requires more care than the final operation of placing concrete at the ultimate point of deposit. With a well-designed mixture delivered with proper consistency and without segregation, placing of concrete is greatly simplified, but even in this case care must be exercised to further prevent segregation and to see that the material flows readily into the corners and angles of forms and around the reinforcement. Constant supervision is essential to insure such complete filling of the form and to prevent the all-too-common practice of depositing continuously at one point, allowing the material to flow to distant points. Even though the material flows sluggishly and is in every respect of proper homogeneity, flowing over long distances will cause segregation especially of the water and fines from the rest of the mass. In spite of the care exercised all along the line it will happen occasionally that an irregular batch, either too stiff or too fluid or possibly with some segregation, reaches the point of deposit. Under these conditions it is particularly important to have adequate supervision of the placing operation, especially where the placing requirements are extremely difficult.

In placing concrete in deep layers a gradual increase in the water content of the upper portion is quite certain to result from the increased pressure on the lower portions. The extra water should be worked to a low point, without actually causing a flow, and removed. It should be remembered that excess water in the upper layer is just as objectionable as excess mixing water.

Attention is called to the significance of a layer of laitance on a section of concrete. It has been a common assumption that if this laitance is completely removed all danger has been eliminated. In fact, specifications frequently place considerable stress on its removal. Laitance can only form from the use of excess water, which means that the upper portion of the section will be porous and the removal of a small layer

of laitance still leaves several inches of porous concrete through which water will pass even under moderate pressure. The effect of this porous layer at the top of each day's work can be seen in many structures subject to water pressure. The lower portion of the layer will be hard and dense while the upper portion shows efflorescence due to passage of water.

Adequate Curing

The effect of curing conditions on the strength and other properties of concrete is discussed in a preceding paragraph where it was shown that by curing the concrete in moisture for the first ten days instead of letting it dry out the strength was increased 75 per cent. From these data it can be seen that the success of very carefully planned work may be largely sacrificed by neglecting the important feature of proper curing.

Rodding concrete in test cylinder mold. See standard method of making concrete specimens.

Provision for this should be as much a part of the field control program as any other. In particular cases it may be best to specify directly the means to be employed and the length of time for which curing shall be continued.

Follow-up Tests

Follow-up tests should be provided for to determine the effectiveness of the field control. These tests should include some tests from each day's operation, also a sufficient number of specimens during an occasional day's operations to determine the daily variation. After the work has been well organized and the quality of concrete being produced is established by these tests the number of specimens and the frequency at which they are taken may be greatly reduced. On long jobs with constant weather conditions after the work is well in hand, only a few tests during the week may be necessary. At the approach of cold weather it is especially important that the test program be such that a full knowledge of the quality of concrete is available at every stage of the construction.

The test cylinders should be made in accordance with the "Standard Methods of Making and Storing Specimens of Concrete in the Field," given on page 29. The adoption of proper curing methods for the specimens, especially in cold weather, is important on account of the effect of temperature. Cylinders may be cured on the work or under uniform temperature in a moist room such as is used in a laboratory. The laboratory curing gives more accurately an indication of the potential quality of the concrete. The field-cured specimens may give a more accurate interpretation of the actual strength in the structure but they offer no explanations as to whether any deficiency in strength is due to errors in proportioning, poor materials or unfavorable curing conditions. The best method, it would seem, therefore, would be to make tests of both field and laboratory stored specimens, especially when the weather is unfavorable, in order that the tests may be properly interpreted.

In making the compression tests on the concrete cylinders the procedure given in "Standard Methods of Making Compression Tests of Concrete" on page 30 should be followed. In general, only the ultimate compressive strengths need be observed. The load indicated by the testing machine, at failure of the test piece, should be recorded and the unit compressive strength calculated in pounds per square inch, the cross-sectional area having been computed from the average diameters of the specimen.

An important factor in the testing of concrete is the moisture content of the specimen. A saturated specimen will show a strength 20 to 30 per cent less than when tested dry. This is of special importance when comparing cores cut from a road slab or structure with specimens cast at the time of placing, as the standard procedure is for the latter to be tested just as they are taken from the moist room or wet sand.

When the time element is important and it is not practicable to wait for the 28-day tests, some of the specimens may be tested at 7 days. An approximate value for the 28-day strength may then be calculated from the equation $S_{28} = S_7 + 30\sqrt{S_7}$, in which S_7 and S_{28} are the compressive strengths at 7 and 28 days respectively.

SPECIFICATIONS FOR CONCRETE

Requiring Definite Water-Cement Ratios and Proper Workability

It is not enough that the engineer himself be thoroughly informed concerning the essentials of concrete construction. He must in addition specify the requirements for his structures in such a way that in the normal execution of the contract these requirements are effectively carried out. The following specification has been drawn to make possible the application to a particular structure of the principles brought out in the preceding chapters of this booklet for the proper design and control of the concrete.

The essential feature of this specification is the specification of quality solely on the basis of the water-cement ratio and proper workability. By leaving to the contractor considerable leeway in the selection of his materials, proportions and consistency and at the same time fixing the water-cement ratio and workability a situation is created whereby the interests of the contractor and the owner are to an unusual degree identical. This situation eliminates friction and creates an atmosphere of mutual understanding that encourages full compliance with the specification and insures concrete of the desired quality.

A specification substantially in this form was used in the construction of the Office and Laboratory Building of the Portland Cement Association erected in 1925-1926. The results obtained in its use were satisfactory in every respect alike to the architect, owner and contractor. With minor modifications the specification is now being used or proposed in numbers of structures.

In view of the important difference between this and the usual specification and the likelihood that many contractors are unfamiliar with some of the problems raised by its use, it is suggested that the specification be accompanied by a foreword, or explanation, setting forth the fundamental considerations involved for the guidance of the contractor in preparing his bid and planning the work. The following form is suggested:

Suggestions to Bidders

Attention of bidders is particularly called to the following concrete specification which differs materially from the ordinary form in that proportions of aggregates are not specified, while a limiting volume of mixing water per sack of cement is fixed.

This form of specification has been adopted because it has been definitely shown by ample tests and construction experience that it is the proportion of mixing water to cement that determines the strength of the concrete, providing only that mixes are plastic and workable and the aggregate clean and structurally sound. This means that so long as the ratio of water to cement remains the same, changing the amount or grading of aggregate does not affect the strength, but only the consistency or workability and the yield of the concrete. Tests and experience have also shown that the production of concrete of high resistance to weathering is dependent upon the use of a mixture of puddling consistency in which the aggregates are thoroughly surrounded by a cement paste of low water-cement ratio. Thus, the water-cement ratio and the workability of the mixture, which determine the strength and durability of the concrete, are made the basis of the specification.

Under this form of specification the contractor is permitted, within certain limits, to use such aggregates and proportions as in his judgment will produce proper economy and workability. By keeping the water-cement ratio constant, uniform strength is assured, while the necessary workability is obtained by varying the aggregate proportions as desired. Increasing the quantity of aggregate for each sack of cement, with its fixed ratio of water, increases the yield of the concrete, but stiffens the mass and may increase the cost of placing. Increased plasticity can be obtained by reducing the amount of aggregates used with each sack of cement, or by changing the proportions of fine to coarse.

Bidders may find that in order to obtain the consistencies to which they have been accustomed more cement will be required per cubic yard than was the case where increased fluidity was obtained by simply adding water. It is, therefore, suggested that trial mixtures be made to determine the cement requirements for the different consistencies which they will use in the various portions of the building. In such trial batches, the moisture contained in the aggregate must be taken into account in securing the water-cement ratio specified.

Attention is further called to the manner in which allowance must be made for batch-to-batch fluctuations in water content. Instead of specifying the average water-cement ratios desired with a definite tolerance, the *maximum permissible* values are specified, requiring the contractor to conduct operations so that these shall not be exceeded. This will enable the contractor to obtain increased economy as methods of controlling the water are perfected, for the smaller the variation the closer the maximum permissible limits can be approximated by the average water content.

The principal difficulties of controlling the mixtures under this type of specification will arise from variations in moisture content and grading of the aggregate, and from inaccuracies in measurement—principally with the sand. The requirement in the specifications, that the source of aggregate be such that uniformity of grading can be assured during any one day's operations, will largely eliminate some of the difficulty. This requirement will be found decidedly to the contractor's interest and one that ordinarily should offer no hardship. If methods of measuring aggregates are adopted which will give uniform quantities from batch to batch, not only will other difficulties be eliminated, but the annoyance of moisture variation in the sand will be considerably minimized. For, with uniformity in quantities of materials and grading, the correct moisture content in the concrete can be gaged with considerable accuracy by the workability or consistency as indicated by the slump test or by appearance of the concrete.

Too much emphasis cannot be placed upon uniformity in the batch-to-batch measurement. For larger jobs or structures where placing requirements are severe, such as the deck of a stadium, almost any plant expenditure that will give uniformity of product would seem to be justified. In the same way, uniformity in the materials will be equally important. For smaller jobs or where the placing can be accommodated to some variation in consistency, heavy plant outlay may not be warranted.

Determinations of the moisture content in the aggregate from time to time will be necessary in order that the water content of the concrete will at all times be within the water-cement ratios specified. The frequency with which these determinations will be required and the consequent annoyance of making the requisite changes in the mix will depend entirely

upon the care used in controlling the grading, uniformity of measurement, and moisture content in the aggregate.

The measurement of moisture in the aggregate within the limit of accuracy specified (1 lb. water in 100 lb. aggregate) should offer no great difficulty. Either drying and weighing a representative sample, or the method of displacement of water, that is, by inundation, will give results satisfactory for the purpose.

Specifications for Concrete and Concrete Materials

Water-Cement Ratio:

Concrete for structural members shall be proportioned to give the necessary workability without exceeding the following quantities of mixing water:

Where concrete of strength* of — lb. per sq. in. is shown on the plans. — U. S. gal. water per sack (94 lb.) of cement.

These water-cement ratios are the maximum permissible. The mixes shall be proportioned for somewhat lower ratios so that with the normal fluctuations from batch-to-batch these ratios will not be exceeded. Moisture held by the aggregate must be included in computing the water-cement ratios. Water absorbed by the aggregate in a period of 30 minutes may be deducted in computing the water-cement ratio.

The water-cement ratios specified shall not be changed except by the Engineer. In the event that the Engineer finds it necessary to change the water-cement ratios from those specified, adjustment covering amount of cement and aggregates affected will be made as an extra or a credit under the provisions of the contract.

Measuring Moisture in the Aggregate:

Moisture in the aggregate shall be measured by a method satisfactory to the Engineer, which will give results within 1 lb. for each 100 lb. of aggregate.

Concrete Proportions and Consistency:

The proportions of aggregate to cement for concrete of the water-cement ratios specified shall be such as to produce concrete that can be puddled readily into the corners and angles of the form and around the reinforcement without excessive spading and without segregation or undue accumulation of water or laitance on the surface. In no case shall concrete be placed which shows a slump outside of the following limits:

Part of Structure	Slump—inches Minimum	Maximum
Caissons	1	4
Heavy walls, slabs, beams	3	7
Thin walls and columns	4	8
Pavements	1	3

Class of Concrete (Expected Strength at 28 days lb. per sq. in.)	Maximum Quantity Mixing Water U. S. gal. per sack of cement (94 lb.)	Type of Structure or Degree of Exposure
3000	6	Roadways, piles, pressure pipe and tanks. Thin structural members in severe exposure. Walls, dams, piers, etc., where exposed to severe action of water and frost.
2500	6¾	Sewers, bridges, walls, dams, piers, etc., for all weather conditions and moderate action of water and frost.
2000	7½	Ordinary enclosed reinforced concrete buildings. Bridges and retaining walls of heavy sections in moderate exposure.
1500	8¼	Mass concrete, basement walls, etc., protected from water or severe weather conditions.

***For general use where resistance to weathering or other agencies must be considered, the following classification is suggested as the basis of the specification. This classification is made with the conditions generally prevailing in Northern United States in mind, and presumes proper workability of the concrete, thorough mixing, placing in a puddling consistency, and thorough protection from drying or freezing during early hardening period.**

The proportion of fine and coarse aggregate shall be such that the ratio of the coarse to the fine shall not be less than — *nor more than —* nor shall the amount of coarse material be such as to produce harshness in placing or honeycombing in the structure. When forms are removed, the surface and corners of the members shall be smooth and sound throughout.

Control of Proportions:

The methods of measuring materials shall be such that the proportion of water to cement can be closely controlled during the progress of the work and easily checked at any time by the Engineer or his representative.

To avoid unnecessary or haphazard changes in consistency, the aggregates shall be obtained from a source which will insure uniform quality and grading during any single day's operation, and they shall be delivered to the work and handled in such a manner that variations in moisture content will not interfere with the steady production of concrete of a reasonable degree of uniformity.

Tests of Concrete:

Frequent tests may be made by the Engineer throughout the work to determine the quality of concrete. These tests will be made at the expense of the owner, and will, in general, be made on 6 by 12-in. concrete cylinders loaded in compression at 7 and 28 days, in accordance with the Standard Method of Making and Storing Specimens of Concrete in the Field (Serial Designation: C31-21) of the American Society for Testing Materials.

The contractor shall cooperate in every way to the end that concrete of the desired quality be obtained. He shall provide, at cost, such housing as may be required for testing equipment and storage of test specimens; such cost to include only labor and materials actually used.

Portland Cement:

Portland cement shall conform to the Standard Specifications and Tests for Portland Cement of the American Society for Testing Materials (Serial Designation: C9-26).

Fine Aggregate:

Fine aggregate shall consist of natural sand having clean, hard, strong, durable, uncoated grains, free from injurious amounts of dust, lumps, soft or flaky particles, shale, alkali, organic matter, loam, or other deleterious substances. The sand shall be of such sizes that it shall all pass a ⅜-in. sieve, at least 15 per cent shall be retained on the No. 8 sieve, and the fineness modulus shall not exceed 3.20.

Coarse Aggregate:

Coarse aggregate shall consist of gravel, crushed stone, crushed air-cooled blast-furnace slag weighing not less than 70 lb. per cu. ft. or other approved inert materials, having clean, hard, strong, durable, uncoated particles free from injurious amounts of soft, friable, thin, elongated or laminated pieces, alkali, organic or other deleterious matter. Coarse aggregate shall not have more than 10 per cent finer than the No. 4 sieve and the maximum size shall not exceed —**.

*** The following limits in the proportion of coarse to fine aggregate are suggested:**

Maximum Size of Coarse Aggregate Inches	Ratio of Coarse to Fine Aggregate on Basis of Dry and Rodded Volumes Minimum	Maximum
⅜	0.4	0.8
¾	0.6	1.5
1 and over	1.0	2.0

**** Maximum size to be filled in by the Engineer.**

Storage of Aggregates:

Aggregates shall be stored so as to avoid inclusion of foreign materials. Frozen aggregate or aggregate containing lumps of frozen materials shall be thawed before using.

Water:

Water for concrete shall be from the city water supply or other approved source.

Mixing Concrete:

The concrete shall be thoroughly mixed in a batch mixer of approved type. The mixer shall be equipped with suitable charging hopper. A water-storage and water-measuring device shall be provided. The mixing of each batch shall continue for at least one minute after all the materials are in the mixer during which time the mixer shall rotate at a peripheral speed of approximately 200 ft. per minute.

Depositing Concrete:

Concrete shall be handled from the mixer to place as rapidly as practicable and in a manner that will prevent segregation of the ingredients. It shall be deposited in the forms as nearly as practicable in its final position to avoid rehandling. Concrete as it is deposited shall be puddled with suitable tools until forms are completely filled and reinforcement and embedded fixtures thoroughly incorporated in the mass.

Concrete shall be deposited continuously and as rapidly as practicable until the unit of operation, approved by the Engineer, is completed.

Concrete when deposited shall have a temperature of not less than 40 degrees F. and not more than 120 degrees F. In freezing weather suitable means shall be provided for maintaining the concrete at a temperature of at least 50 degrees F. for 72 hours or more after placing, or until the concrete has thoroughly hardened. The methods of heating the materials and protecting the concrete shall be approved by the Engineer. Salt, chemicals, or other foreign materials shall not be mixed with the concrete for the purpose of preventing freezing.

Protection of Concrete:

Exposed surfaces of concrete shall be protected from drying for a period of at least 7 days after being deposited.

DESIGN OF MIXTURES BY THE CALCULATION METHOD

The fact that the size and grading of the aggregates bear an important relation to the workability and strength of the concrete has long been recognized and various attempts have been made to evaluate these in a quantitative way, generally based in some manner on the sieve analysis. In the investigations carried out at the Structural Materials Research Laboratory* a method of expressing size and grading of aggregate was developed which makes it possible to compare the different gradings for use in concrete. This measure of the size and grading is also based on the sieve analysis and is termed the "fineness modulus."

In these investigations it was shown that a fairly regular relation exists between the "fineness modulus" of the aggregate and the quantity of mixing water for a given mix and condition of plasticity. Because of this relationship it is possible to use the "fineness modulus" as a basis for the design of the mixture with the water-cement ratio as the criterion of strength. From these experimental data tables and diagrams have been prepared, showing the interrelation between fineness modulus, mix and strength (in terms of the water-cement ratio) for different consistencies; also the limits of fineness modulus for different mixes beyond which harsh or non-workable mixes will result. With these data the design of the mixture consists in selecting the water-cement ratio to meet the strength requirements or conditions of exposure, and from the diagrams or tables finding the mix corresponding to the limiting fineness modulus and the required plasticity or workability. With this information all that is required is to find the relative proportion of fine and coarse aggregate to give the required fineness modulus and to express the mix in terms of separated aggregates as they will be handled on the work.

In the following paragraphs the fineness modulus is defined and its relation to strength and workability of concrete of different mixes is shown. Following this the detailed procedure in selecting the mix and translating it into the field mix is explained with an illustrative example.

In using this method of design it is important to realize that, while the relationships established are quite general and applicable to a wide range of materials, they do not apply with exactness to all materials. If the mix and limiting fineness modulus selected in any given case do not give the necessary workability they should be adjusted *without altering* the water-cement ratio. *It is the water-cement ratio and the workability of the concrete that insures proper strength and resistance to weathering, not the fineness modulus or the mix.*

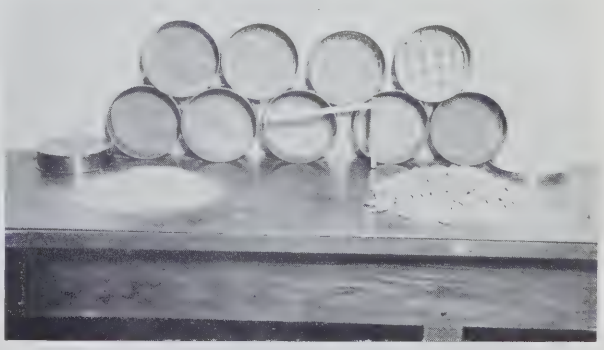

Fig. 9
Standard set of laboratory sieves.

* See footnote on page 7.

Fineness Modulus Defined

The fineness modulus is the sum of the percentages in the sieve analysis divided by 100, when the sieve analysis is expressed as percentages* coarser than the following square mesh sieves:

Sieve No. or Size	100	50	30	16	8	4	⅜	¾	1½
Clear Open.—in.	.0059	.0118	.0236	.047	.094	.188	.375	0.75	1.5

This set of sieves is known as the Tyler standard set. The clear opening in each sieve is double the opening in the next smaller sieve. When larger aggregates are used the 3 and 6-in, sieves may be added.

TABLE IV

TYPICAL SIEVE ANALYSES OF AGGREGATE

Size of Sieve	Per Cent Coarser than Each Sieve: Sand	Screenings	Stone	Pebbles
1½	0	0	0	0
¾	0	0	40	15
⅜	0	0	100	45
4	20	0	100	100
8	35	25	100	100
16	55	35	100	100
30	70	75	100	100
50	90	80	100	100
100	100	85	100	100
Fineness Modulus	3.70	3.00	7.40	6.60
Range in Size	0-⅜ in.	0-4	⅜-1½	4-1*

*1 and 2-inch sieves are used in determining size of aggregate but are not used in calculating fineness modulus.

Table IV, above, shows typical sieve analyses of aggregates. If the sieve analysis is made, using another series of sieves, the percentages for the above sieves may be obtained by interpolation from a sieve analysis curve. See Fig. 10. The method of making the sieve analysis is described on page 22. See also "Standard Method of Test for Sieve Analysis of Aggregates for Concrete" of the American Society for Testing Materials (Serial Designation C41-24) given on page 28. A few trial calculations will show that the fineness modulus becomes greater as the aggregate becomes coarser and also that the same fineness modulus may be obtained from an infinite number of sieve analyses.

Relation of Fineness Modulus to Quantity of Mixing Water

Tests have shown that most aggregates having the same fineness modulus and similar shapes and surface characteristics require approximately equal amounts of mixing water for a given plasticity and consequently will produce concrete of the same strength, so long as other conditions are equal and the aggregate is not too coarse for the quantity of cement used. Concrete of sharp broken stone with rough faces requires more water for the same fineness modulus and workability than when rounded smooth pebbles are used.

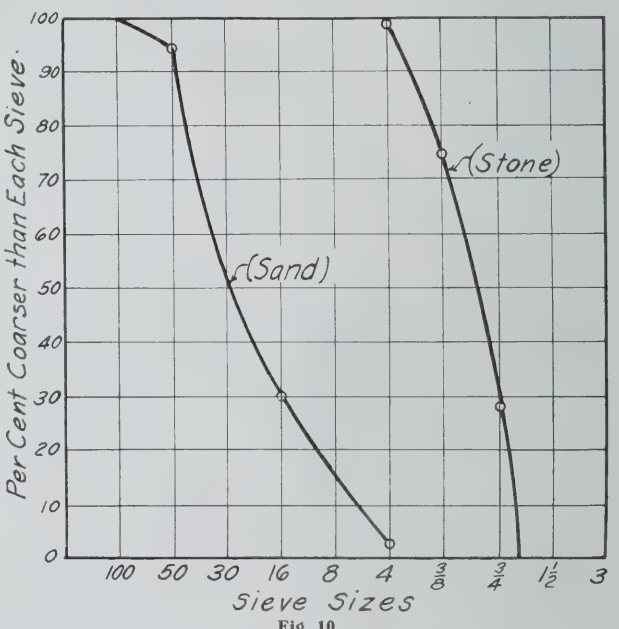

Fig. 10

Sieve analysis curves.

A typical relation between the fineness modulus of the aggregate and the strength of the concrete is shown in Fig. 11. Each combination of aggregates indicated in this diagram required different amounts of mixing water to give the same consistency, as measured by the slump, thus resulting in differences in strength. It will be noted from this curve that the strength increased with the fineness modulus until the grading of the aggregate became too coarse for the amount of cement used beyond which the strength was lowered. The increase in strength with fineness modulus shows that less water is required for the coarse mixtures. The falling off in strength beyond a certain fineness modulus indicates that the limit of workability has been passed.

Fineness Modulus of Combined Aggregates

The fineness modulus of a mixture of two or more aggregates or the proportions in which to mix them to give a required fineness modulus can be calculated from the fineness moduli of the individual aggregates. The fineness modulus of a mixture of fine and coarse aggregates may be expressed by the following formula:

* For average aggregates the percentage may be calculated by weight. The fineness modulus is, however, based on absolute volumes and in determining the fineness modulus of a mixture of two or more aggregates having a large difference in unit weight or specific gravity these factors must be taken into account. Thus in equation 1, r will be the ratio of the absolute volume of fine aggregate to the sum of the absolute volumes of fine and coarse aggregates. The absolute volume $= \frac{\text{unit weight}}{\text{specific gravity} \times \text{unit weight of water}}$. With the usual mixtures of sand and pebbles or crushed stone the method of determining fineness modulus given here is sufficiently accurate for practical purposes.

$m = rm_f + (1-r)\, m_c$ (Equation 1)

where

m = fineness modulus of mixed aggregate
m_f = fineness modulus of fine aggregate
m_c = fineness modulus of coarse aggregate
r = ratio of volume of fine aggregate to the sum of the volumes of fine and coarse aggregates measured separately.
(1−r) is the ratio of coarse aggregate.

In a 1:2:4 mix $r = \frac{2}{2+4} = 0.33$

The ratio of fine aggregate to the separate volumes of fine and coarse aggregates necessary to produce a required fineness modulus may be calculated from another form of the same equation as follows:

$$r = \frac{m_c - m}{m_c - m_f} \quad \text{(Equation 2)}$$

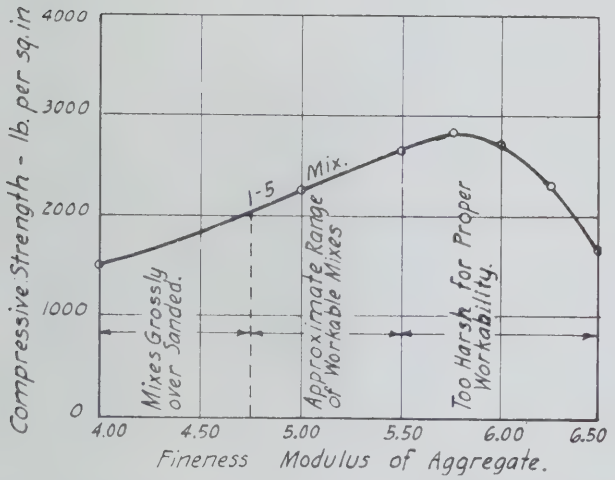

Fig. 11

Typical curve showing the effect of grading of aggregate on the compressive strength of concrete. The coarser the aggregate (higher fineness modulus) the higher the strength because less water is required for a workable mix. With aggregate too coarse for proper workability the strength is reduced.

Quantity of Cement—(The Mix)

The common method of expressing the quantity of cement is in terms of the volume of aggregates measured separately. For example, a 1:2:4 mix represents 1 volume of cement, 2 volumes of fine aggregate and 4 volumes of coarse aggregate. The sack of cement which in the United States* weighs 94 lb. is assumed to be 1 cu. ft. The common practice is to express the quantity of aggregate in terms of loose volumes as measured on the job. In this booklet proportions expressed in this way are termed the "field mix." This makes for lack of uniformity as the actual quantity of aggregates will vary with the method of measurement and particularly with the moisture condition of the aggregate. A given volume of dry sand may contain as much as 30 per cent more material by weight than the same volume of damp sand. For the sake of uniformity, therefore, it is necessary to select a standard method of measuring volumes of aggregate which can be used as a basis of reference. The American Society for Testing Materials has selected such a method described on page 28. Even with proportions expressed in terms of separated volumes of aggregates measured in accordance with this standard method there still remains another variable, the proportions of the two sizes of aggregates. It is desirable, for the purpose of these calculations, to state the proportions in terms of the cement and volume of "mixed" aggregates measured dry and rodded in accordance with the standard method. This is termed a "real mix." For example, a field mix of 1:2:4 would be equivalent to a mix of 1:1.6:3.7 of dry, rodded aggregates if the fine aggregate bulked 25 per cent and the coarse aggregate 8 per cent, due to moisture and method of measuring. The real mix for these proportions would be about 1:4.4, the volume of mixed aggregate being, for average conditions, about 86 per cent of the volume of separated materials.

Inter-relation of Workability, Grading, Mix and Strength

As pointed out above, while the water-cement ratio is the factor which controls the strength of the concrete, the mix, consistency and fineness modulus of the aggregate bear definite relations to each other for a fixed water ratio. Figs. 12 and 13 show the interrelation of these three factors. The consistency is represented by the slump. Four sets of diagrams are shown in each figure, including ranges in slump from ½ in. to 10 in.

As the curves in these diagrams are used in the design of mixes it is essential to have a clear understanding of their basis and limitations. This is desirable also, as when well understood these diagrams are very useful in the general study of concrete mixtures and in answering many of the questions that arise in the comparison of different aggregates or mixes.

The diagrams are based on the extensive tests made at the Structural Materials Research Laboratory*, covering a wide range of mixes and a variety of aggregate types and sizes. The grading of the aggregates was generally quite uniform from minimum to maximum size. The point of intersection of two curves in the diagram represents the mix (to the scale at the left) and the fineness modulus (to the scale at the bottom) for which the amount of mixing water represented by the strength curve will give the consistency indicated in the title of the diagram (slump) when the maximum size of the aggregate is that shown by the other intersecting curve. The strength values given on the curves in Fig. 12 are taken from curve "A" of Fig. 1, while those in Fig. 13 are taken from curve "B." Either Fig. 12 or Fig. 13 may be used, depending upon whether curve "A" or curve "B" is used in the selection of the water-cement ratio.

* In Canada a sack of cement weighs 87½ lb.

* See footnote page 7.

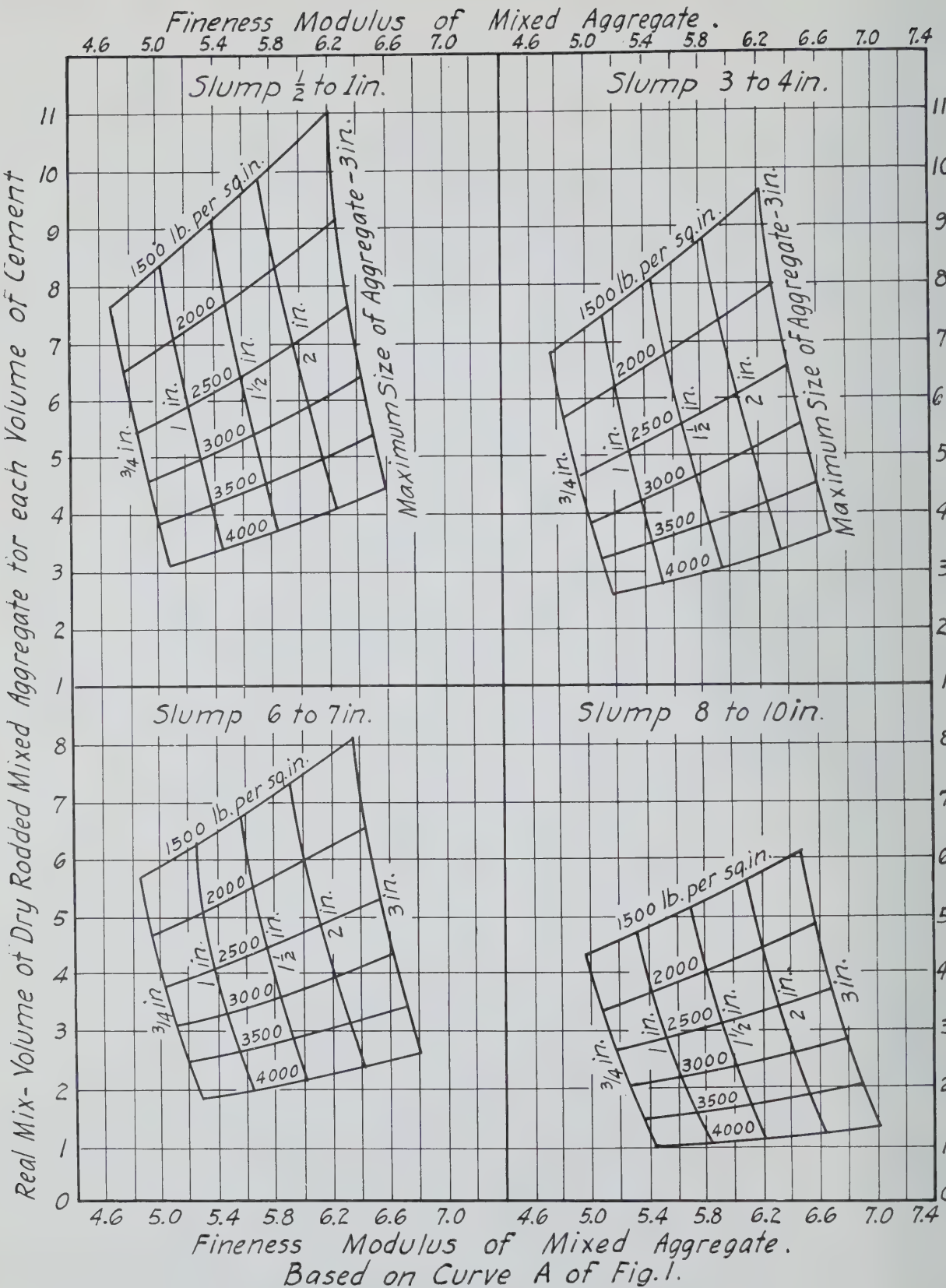
Fineness Modulus of Mixed Aggregate.
4.6 5.0 5.4 5.8 6.2 6.6 7.0 7.4
Slump ½ to 1in.
Slump 3 to 4in.
Slump 6 to 7in.
Slump 8 to 10in.
1500 lb. per sq.in.
2000
2500
3000
3500
4000
¾ in.
1 in.
1½ in.
2 in.
3 in.
Maximum Size of Aggregate
Real Mix- Volume of Dry Rodded Mixed Aggregate for each Volume of Cement
0 1 2 3 4 5 6 7 8 9 10 11
Fineness Modulus of Mixed Aggregate.
Based on Curve A of Fig. 1.

Fig. 12

Diagram showing relation between strength of concrete, grading of aggregate, mix and consistency on the basis of Curve A, Fig. 1. The strengths indicated correspond to the water-cement ratios which give for the different mixes the consistencies shown. The values are based on rounded pebble aggregate uniformly graded from 0 to the size indicated. The curves for aggregate size are drawn to represent the maximum values of fineness modulus for proper workability with these aggregates. The maximum values for fineness modulus for harsher aggregates such as crushed stone or slag, flat pebbles or stone screenings should be about 0.25 lower. In designing mixtures with such materials proceed as if these curves of maximum size were 0.25 to the left.

For mass concrete somewhat higher values than those indicated in the figure may be used.

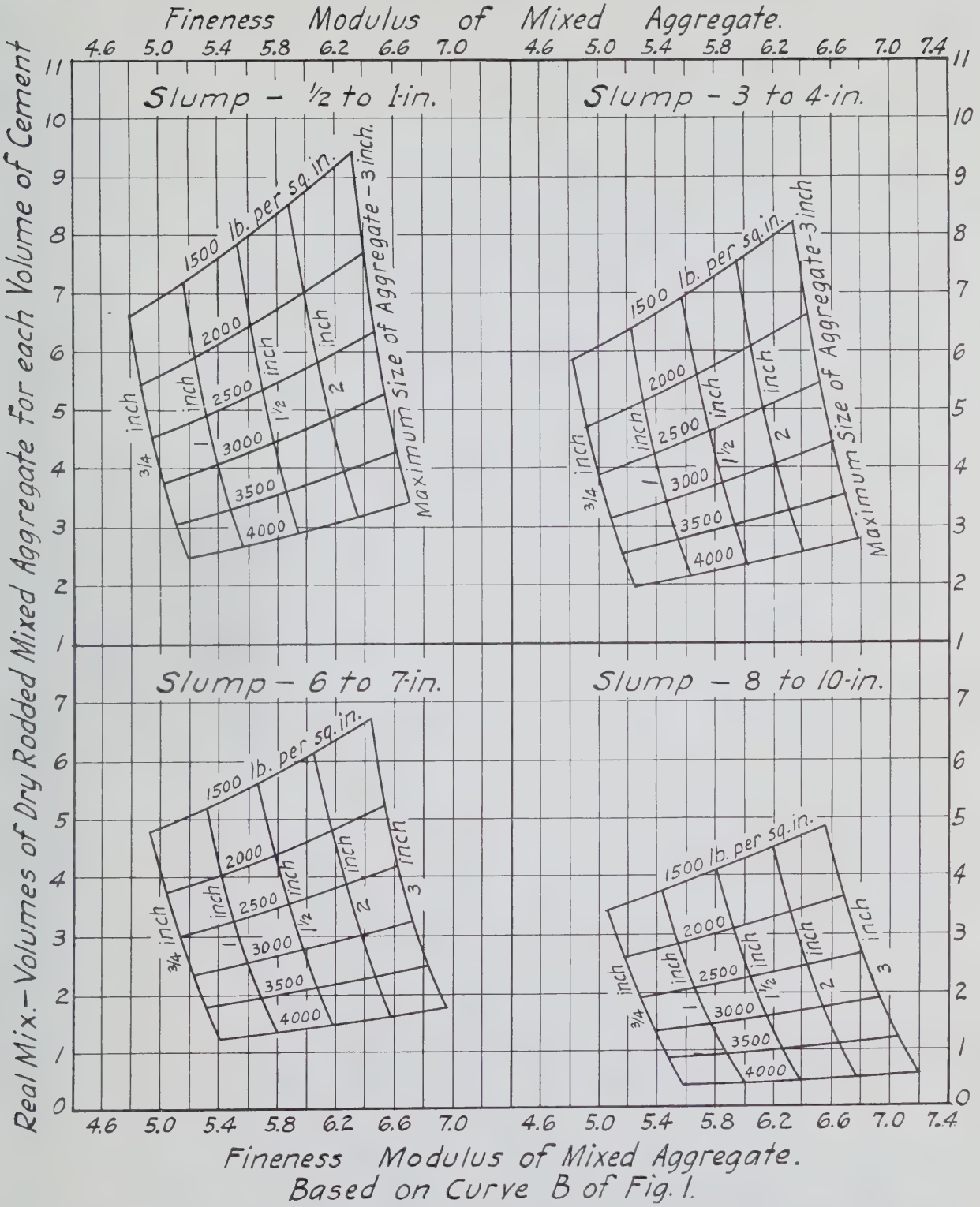

Fig. 13

Diagram showing relation between strength of concrete, grading of aggregate, mix and consistency on the basis of Curve B, Fig. 1. The strengths indicated correspond to the water-cement ratios which give for the different mixes the consistencies shown. The values are based on rounded pebble aggregate uniformly graded from 0 to the size indicated. The curves for aggregate size are drawn to represent the maximum values of fineness modulus for proper workability with these aggregates. The maximum values for fineness modulus for harsher aggregates such as crushed stone or slag, flat pebbles or stone screenings should be about 0.25 lower. In designing mixtures with such materials proceed as if these curves of maximum size were 0.25 to the left.

For mass concrete somewhat higher values than those indicated in the figure may be used.

In using these diagrams as a basis of design it should be remembered that the exact slump indicated may not result from using the given water-cement ratio with the mixes shown for the different fineness moduli, owing to the important effect on the slump of minor differences in grading, shape or surface characteristics of the aggregate. The best way is to use the diagrams for a preliminary selection of the mix, then in trying it out use the exact water-cement ratio, making such adjustments in the mix as are found necessary to give the desired slump or workability.

Tests of Aggregates

Before proceeding with the design of a mixture it is necessary to make the following tests on the aggregates:

Tests for cleanness and quality.
Test for moisture content.
Sieve analyses to determine fineness modulus and maximum size.
Unit weight tests on fine, coarse and mixed aggregates.

The tests for cleanness and quality and the method of making moisture determinations have been described in the general discussion of the methods of designing mixtures.

Sieve Analysis and Fineness Modulus

About 1¼ lb. of fine and 25 lb. of coarse aggregate should be selected by the quartering method for sieve analyses. The samples should be thoroughly dried. Separate the aggregates into the various sizes by means of the set of standard sieves. Sieve all sizes to point of practical refusal. The point of refusal can best be determined by sieving the material onto a sheet of white paper, cleaning the paper at intervals and noting when the amount passing the sieve becomes negligible.

Obtain the weight of the total amounts coarser than each sieve and express them as percentages (by weight) of the total sample. Add these percentages and divide the sum by 100. This sum is the fineness modulus. The typical sieve analyses in Table IV indicate the method of calculating the fineness modulus.

Determination of Maximum Size

To apply the data in Figs. 12 and 13 it is necessary to use a standard method of determining the maximum size of the aggregate. In order that a certain screen may be considered the maximum size at least 15 per cent must be retained on the next smaller screen. In this determination the 1-in. and 2-in. screens are used in addition to the standard set.

The maximum size of the aggregate shown in these charts is the maximum size of the combined aggregate. In most cases this is the same as the maximum size of the coarse aggregate. Sometimes it will be the next smaller size, in which event it may be necessary to design the mix a second time, using the lower value.

Unit Weights of Fine, Coarse and Mixed Aggregates

Determine the weights per cubic foot of the aggregates, damp and loose, duplicating as nearly as possible the actual conditions that will occur on the job.

Next dry the samples and determine the unit weights of the fine, coarse and mixed aggregates, in accordance with the "Standard Method of Test for Unit Weight of Aggregate for Concrete," given on page 28. Since the proportions in which to mix the aggregates are not known they may be mixed in several proportions, obtaining the unit weight of each combination and plotting the results. A curve similar to the curve in Fig. 14 can then be drawn. The unit

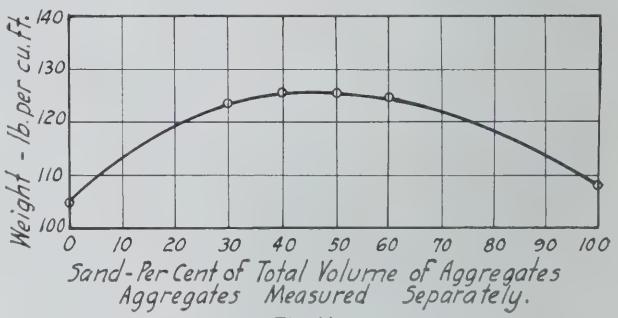

Fig. 14
Typical unit weight curve for different proportions of fine and coarse aggregates.

weight of any combination of the aggregates can be read directly from this curve. The following proportions are suggested:

Fine Aggregate Per Cent	Coarse Aggregate Per Cent
30	70
40	60
50	50
60	40

The importance of basing calculations on materials in a standardized condition (dry and rodded) can be better appreciated by bearing in mind that dry sand, not rodded, may weigh 5 to 10 per cent less than when rodded; also that damp sand, when measured loose, will swell or "bulk" as much as 25 to 35 per cent, due to the presence of moisture. Coarse aggregates do not "bulk" to an appreciable extent because of the moisture content; however, a given volume, rodded, may weigh 5 to 10 per cent more than when measured loose.

Steps in the Design

With the above data on the aggregates the steps in the design of a mix are as follows:

1. Determine from Fig. 12 or 13 the real mix and the corresponding fineness modulus for the given strength, size of aggregate and desired slump.
2. Calculate the field mix.

To assist in explaining these steps in the design an example will be given below and the necessary calculations made in each step. Assume, for this example, that the concrete is to be used in the construction of

a reinforced concrete building and the following data have been obtained:

Strength of concrete must be 2000 lb. per sq. in. at 28 days.
Water-cement ratio corresponding to the strength from curve "B," 0.90.
Slump necessary to place the concrete properly, 6 to 7 in.

Fine Aggregate

Fineness Modulus, 2.5.
Size 0—No. 4.
Weight damp, loose, 90 lb. per cu. ft.
90 lb. damp, loose = 87 lb. when dry.
Moisture, 3 lb. per cu. ft. of damp, loose material.
Weight dry, rodded, 108 lb. per cu. ft.

Coarse Aggregate

Fineness Modulus, 7.0.
Size No. 4—1½ in.
Weight damp, loose, 100 lb. per cu. ft.
100 lb. damp, loose = 98 lb. when dry.
Moisture, 2 lb. per cu. ft. of damp, loose material.
Weight dry, rodded, 105 lb. per cu. ft.

The Real Mix and Fineness Modulus of Mixed Aggregates

From the curves for the slump range of 6 to 7 in. (Fig. 13, lower left) find the point of intersection of the curve representing a strength of 2000 lb. per sq. in. with the curve of 1½ in. maximum size of aggregate. Proceed horizontally to the left marginal scale. A real mix of 1:4.4 is indicated. From the same intersection of the curves for strength and maximum size drop vertically to the lower marginal scale. The maximum value of the fineness modulus of the mixed aggregate is found to be 5.8. Should it be desirable to use a lower fineness modulus than this the same curve representing the strength should be used in determining the real mix.

The Field Mix

The real mix proportion of 1:4.4 means that for each volume of cement 4.4 volumes of mixed aggregates measured in the standard method (dry rodded) are used. To convert these proportions into the corresponding proportions to be used in the field it is necessary to determine the percentages of fine and coarse aggregates to produce the desired fineness modulus of the mixed aggregate, the shrinkage in volume when the aggregates are mixed in these proportions, and correct for the bulking due to moisture and loose measurement of the materials.

The ratio of volume of fine aggregate to the sum of the volumes of fine and coarse aggregate measured separately may be calculated from equation 2. Thus, for a fineness modulus of 5.8 for the combined aggregate, the proportion of sand is:

$$r = \frac{7.0 - 5.8}{7.0 - 2.5} = 0.27$$

That is, 27 per cent of the total volume of separate aggregates is sand and 73 per cent is stone.

The weight of a cubic foot of the given aggregates combined in the above proportions may be determined from a curve similar to the one shown in Fig. 14. Assume for this example that it is found to be 123 lb. per cu. ft.

The volume of aggregates required when measured separately may be obtained by comparing this weight with the weight of a cubic foot of the separated aggregates in the same proportions. Thus in this example:

.27 cu. ft. sand weighing 108 lb. per cu. ft. = 29.16 lb.
.73 cu. ft. stone weighing 105 lb. per cu. ft. = 76.65 lb.

Total 105.81 lb.

Since a cubic foot of the mixed aggregates in these proportions weighs 123 lb. it will require $\frac{105.81}{123} = .86$ volumes of mixed aggregate to correspond to one volume of the aggregates measured separately. In this example the real mix is 1:4.40. This means that $\frac{4.40}{.86}$ or 5.10 cu. ft. of aggregates, measured separately, must be used to equal the real mix of 4.40.

The correction for bulking, due to moisture and to loose measurement, may be calculated from the unit weights of the aggregates measured as on the job and measured in accordance with the standard method (dry and rodded). From the above data 90 lb. of damp, loose sand (87 lb. sand plus 3 lb. water) is equivalent in volume to 108 lb. of dry, rodded sand. It will therefore require $\frac{108}{87}$ cu. ft. of damp, loose sand for each cubic foot of the dry, rodded sand. In a similar manner it will require $\frac{105}{98}$ cu. ft. of damp, loose stone for each cubic foot of dry rodded stone.

The proportions of the materials to be used in the field will, therefore, be:

Sand, damp and loose $= 5.10 \times 0.27 \times \frac{108}{87} = 1.71$

Stone, damp and loose $= 5.10 \times 0.73 \times \frac{105}{98} = 4.00$

Thus the Field Mix is 1:1.71:4.00.

Checking and Redesigning the Mix

It may be found that the mixture as designed, when used with some aggregates, will not produce concrete of the desired workability. In this event the proper additions may be made before discharging the mixer. Sand or coarse aggregate or both may be added if the mix appears to be too wet. If the concrete is too stiff, cement and water in the proper proportion may be added.

The effect of adding a quantity of sand can be calculated by following the methods described. The mixed aggregate in the above example has a fineness modulus of 5.8. Increasing the sand to 35 per cent will reduce the stone to 65 per cent and change this fineness modulus to 5.4 as determined by equation 1.

Then from Fig. 13, with a fineness modulus of 5.4 and a desired strength of 2,000 lb. per sq. in. at 28 days, the new mix is found to be 1:4.0. With this new mix, the yield and field mix can be calculated in the manner previously outlined.

Corrections for Absorption and Moisture

The water-cement ratio determined on page 23 is 0.90. This is equivalent to 7.48 (U. S. gal.* per cu. ft.) $\times$ 0.90 = 6.73 gal. of water per sack of cement. This is the total amount of water to be used and must be corrected for absorption and for water already contained in the aggregate.

Assume the absorption of the sand and stone in question as 1 per cent by weight. The water to be added to take into account this absorption will be:

For the sand 1.71 $\times$ 87 $\times$ .01 = 1.49 lb. = 0.18 gal.

For the stone 4.00 $\times$ 98 $\times$ .01 = 3.92 lb. = 0.47 gal.

Total = 0.65 gal. for each sack of cement.

The moisture content has been determined as 3 lb. per cu. ft. of sand and 2 lb. per cu. ft. of stone as used in the field. The deductions for moisture content will therefore be:

For the sand 1.71 $\times$ 3 = 5.13 lb. = 0.62 gal.

For the stone 4.00 $\times$ 2 = 8.00 lb. = 0.96 gal.

Total = 1.58 gal. for each sack of cement.

The net quantity of water to be added at the mixer for each sack of cement therefore will be:

6.73 + 0.65 − 1.58 = 5.80 gal.

Quantities of Materials Required

An accurate method of determining the quantities of materials in concrete based on the weights and specific gravities of the materials is given on page 11.

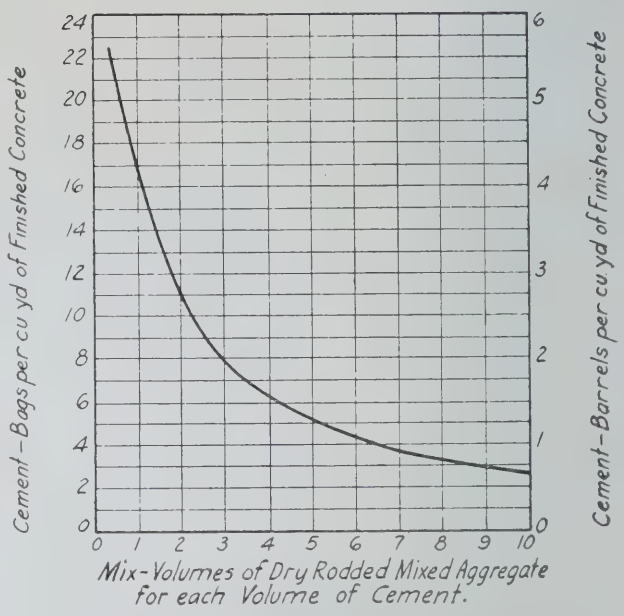

Fig. 15

Cement required for one cubic yard of finished concrete. Values are net quantities with no allowance for waste.

A close approximation of the quantity of cement required per cubic yard of concrete for a given real mix can be obtained from Fig. 15 which is based on quantities determined in the laboratory for various mixtures. For the real mix of 1:4.4 this figure shows that 5.8 sacks (or 1.45 barrels) of cement are required for each cubic yard of finished concrete.

Then the fine and coarse aggregates required are:

5.80 $\times$ 1.71 = 9.92 cu. ft. = 0.37 cu. yd. of damp, loose sand per cu. yd. of finished concrete.

5.80 $\times$ 4.00 = 23.20 cu. ft. = 0.86 cu. yd. of damp, loose stone per cu. yd. of finished concrete.

Field Equipment Required for the Design and Control of Concrete Mixtures

(When the Calculation Method is Used)

1—Set of Standard sieves with cover and pan; sizes: 100, 48, 28, 14, 8, 4, $\frac{3}{8}$ in., $\frac{3}{4}$ in., **1 in., $1\frac{1}{2}$ in., 3 in.

1—Lever scale, capacity 70 lb., weighing to .01 lb. or $\frac{1}{4}$ ounce.

1—Four pound precision postal scale.

Three or four pans for drying aggregates.

1—Decantation pan. (See A. S. T. M. Standards.)

2—Colorimetric bottles. (See A. S. T. M. Standards.)

1—Thirty-two ounce graduated prescription bottle (for Sedimentation Test).

1—Oven or heater for drying aggregates.

1—Scoop for sampling aggregates. A sugar scoop with wooden back and strong wooden handle is very satisfactory for this purpose.

1—Piece of canvas or heavy oilcloth 5 or 6 ft. square for use in sampling and mixing aggregates.

2—Measuring receptacles for determination of unit weights of aggregates. (See A. S. T. M. Standards.)

2—Heavy mason's trowels, with at least 10-in. blade, cut off to leave blunt end about 3 or 4 in. across.

1—Slump cone.

Truncated cone, 4 in. top diameter, 8 in. bottom diameter, 12 in. high, handles and footpieces on sides, made of No. 20 gauge galvanized metal.

1—$\frac{5}{8}$ in. round steel rod, 24 in. long, pointed at one end.

6 x 12-in. cylinder molds as required.

These molds must not vary over $\frac{1}{16}$ in. in diameter or height. They must be non-absorbent and are best made from cold drawn seamless steel tubing. Cheaper molds can be made of No. 20 gauge galvanized iron. Molds made of heavy waxed board may also be used if care is taken to prevent deformation when molding. These latter molds have the advantage that they may also be used to act as containers during curing and shipping to the testing laboratory. Molds of this size should not be used for concrete containing aggregate particles larger than about 2 in. (See A. S. T. M. Standards.)

8 x 16-in. cylinder molds as required.

These will be required only when the concrete contains aggregate particles larger than 2 in. The same specifications in general apply as for 6 x 12-in. molds.

Machined cast iron plates, 9 in. diameter, $\frac{1}{2}$ in. thick. Both sides should be machined and plate should be of even thickness.

1—Stiff bristle brush for cleaning equipment.

Oil—Quantity of heavy crude oil for treating cast iron plates and cylinder molds.

* **In Canada the unit of measure is the imperial gallon. The imperial gallon is equivalent to 1.2 U. S. gal.**

** **Used in determination of maximum size only. Not used in determination of fineness modulus.**

STANDARD SPECIFICATIONS AND TESTS FOR CONCRETE AND CONCRETE AGGREGATES

of the

AMERICAN SOCIETY FOR TESTING MATERIALS PHILADELPHIA, PA.

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Tentative Specifications for Concrete Aggregates

Serial Designation: C 33—23 T

FINE AGGREGATE

1. Fine aggregate shall consist of sand, stone screenings, or other inert materials with similar characteristics, or a combination thereof, having clean, hard, strong, durable, uncoated grains, free from injurious amounts of dust, lumps, soft or flaky particles, shale, alkali, organic matter, loam or other deleterious substances.

2. Fine aggregate shall preferably be graded from fine to coarse, with the coarser particles predominating, within the following limits:

Passing ⅜-in. sieve	100 per cent
Passing No. 4 sieve	85 "
Passing No. 50 sieve	not more than 30 "
Weight removed by decantation test	not more than 3 "

The sieves shall conform to the requirements specified in the Standard Method of Test for Sieve Analysis of Aggregates for Concrete (Serial Designation: C 41-24) of the American Society for Testing Materials.

3. The fine aggregate shall be tested in combination with the coarse aggregate and the cement with which it is to be used and in the proportions, including water, in which they are to be used on the work, in accordance with the requirements specified in Section 6. In case the test provided in Section 6 shows the strengths specified therein, the fine aggregate shall be considered acceptable.

4. With the approval and consent of the Engineer, the following requirements may be substituted:

(*a*) Mortar briquettes, cylinders or prisms, consisting of one part by weight of portland cement and three parts by weight[1] of fine aggregate, mixed and tested in accordance with the methods described in the Standard Specifications and Tests for Portland Cement (Serial Designation: C 9) of the American Society for Testing Materials,[2] for tension tests and in accordance with the Tentative Specifications and Tests for Compressive Strength of Portland Cement Mortars (Serial Designation: C 9—16 T) of the American Society for Testing Materials [3] for Compression tests shall show a tensile or compressive strength at the age of 7 and 28 days not less than that of 1:3 standard Ottawa sand mortar of the same consistency made with the same cement.

NOTE: In testing aggregates, care should be exercised to avoid the removal of any coating on the grains which may affect the strength; bank sand should not be dried before being made into mortar, but should contain natural moisture. The percentage of moisture may be determined upon a separate sample and the weight of the sand used in the test corrected for the moisture content.

(*b*) Upon failure to meet this requirement, the proportion of cement in the concrete mixture shall be increased or the proportions of cement, fine aggregate, coarse aggregate and water changed in such a way as to produce the strength specified in Section 6.

5. No fine aggregate showing a color darker than the standard color when tested in accordance with the Standard Method of Test for Organic Impurities in Sands for Concrete (Serial Designation: C 40-22) of the American Society for Testing Materials shall be used unless the strength requirement of Sections 4 or 6 is fulfilled.

6. The grade of concrete required with its compressive strength in pounds per square inch shall be specified by the Engineer. The concrete materials, including cement, fine aggregate, coarse aggregate and water, mixed in the proportions in which they are to be used in the work, and tested in accordance with the standard methods of test, shall at 28 days develop a strength of not less than that specified for the grade of concrete required. Upon failure to meet this requirement, the proportion of cement in the concrete mix shall be increased or the proportions of cement, fine aggregate, coarse aggregate and water shall be changed in such a way as to produce the specified strength.

COARSE AGGREGATE

7. Coarse aggregate shall consist of crushed stone, gravel, air-cooled blast-furnace slag, or other approved inert materials with similar characteristics, or a combination thereof, having clean, hard, strong, durable, uncoated pieces free from injurious amounts of soft, friable, thin, elongated or laminated pieces, alkali, organic or other deleterious matter.

8. In the case of blast-furnace slag, the weight per cubic foot shall not be less than 65 lb. per cu. ft. for use in concrete structures not subject to abrasion, and not less than 70 lb. per cu. ft. for use in concrete floor or road construction.

9. (*a*) Coarse aggregate shall be well graded from fine to coarse within the following limits: [4]

Passing ..... in. sieve (maximum size)	95 per cent
Passing ..... in. sieve (intermediate size)	to ... per cent

Not more than 15 per cent shall pass the No. 4 sieve; not more than 5 per cent shall pass the No. 8 sieve.

(*b*) The maximum size of coarse aggregate shall be either designated by the Engineer or indicated on the plans.

NOTE. The grading as above specified is intended to secure uniformity of aggregate, but will be governed by local conditions. The following table indicates desirable gradings, in percentages, for coarse aggregate for certain maximum sizes:

Maximum Size of Aggregate, inches	Square Openings, inches							Per Cent Passing No. 4 Sieve, not more than	Per Cent Passing No. 8 Sieve, not more than
	3	2½	2	1½	1	¾	½		
3	95	..	..	40–75	..	..	..	15	5
2½	..	95	..	..	..	..	..	15	5
2	..	..	95	..	40–75	..	..	15	5
1½	..	..	..	95	..	40–75	..	15	5
1	..	..	..	..	95	..	40–75	15	5
¾	..	..	..	..	..	95	..	15	5

Standard Methods of Sampling Stone, Slag, Gravel, Sand and Stone Block for Use as Highway Materials Including Some Material Survey Methods

Serial Designation: D 75—22

These methods were approved July 18, 1924, as "Tentative American Standard" by the American Engineering Standards Committee.

1. Samples of all materials for test upon which is to be based the acceptance or rejection of the supply shall be taken by the Engineer or his authorized representative. Samples for inspection or preliminary test may be submitted by a producer or owner of the supply.

[1] When approved by the Engineer, these proportions may be by volume, assuming 1 cu. ft. of cement to weigh 94 lb.

[2] 1924 Book of A. S. T. M. Standards.

[3] Proceedings, Am. Soc., Testing Mats., Vol. XX, Part 1, p. 599 (1920).

[4] When there are several suitable aggregates available, a thorough investigation of the relative economy of each for producing concrete of the desired strength is advisable, especially for work of considerable magnitude.

I. Sampling of Stone

A. Sampling of Stone from Ledges or Quarries for Quality.

2. The ledge or quarry face shall be inspected closely to determine any variation in different layers. Any difference in color or structure shall be observed, and, if necessary to secure unweathered specimens, pieces broken from different layers.

3. (*a*) For standard stone test, separate samples shall be taken of at least 30 lb. each of fresh unweathered specimens from all layers that appear to vary in color or structure. When more than one piece is taken, the minimum size shall be 2 in., except that there shall be one piece of each sample of a minimum size of 4 by 5 by 3 in. on which the bedding plane is marked and which shall be free from seams or fractures to be used in the toughness or compression test.

(*b*) The sample for concrete test will depend on the kind of tests to be made and the number of specimens necessary.

4. In addition to the general information accompanying all samples, samples from local ledges not commercial sources shall contain the following: Name of owner; approximate quantity available (if quantity is very large this can be recorded as practically unlimited); amount and character of overburden or stripping; haul to nearest point on road where the material is to be used; character of haul (kind of road and grade); also some detailed record of the extent and location of the material represented by each sample. For this purpose a sketch, plan and elevation showing the thickness and location of the different layers is recommended.

B. Sampling of Stone from Commercial Quarries.

5. Where practical, samples from commercial quarries shall be taken from the ledge or quarry face and the same procedure shall be followed as when sampling local ledges.

6. At the plant, the following factors affect the size of broken stone: Size and shape of screen openings; length of screen sections; the angle of screen with horizontal; the speed of screen rotation; and the rate at which the screen is fed. A general inspection and record of these conditions shall be made. The sample shall be taken preferably from cars or boats while loading from stock piles or bins. It is recommended, in order that the sample may be representative, that separate samples be taken at different times while the material is being loaded. If the sample has to be taken from the bin or stock pile, several samples shall be taken from different parts of the stock pile and from the top of the bin and the loading chute. These separate samples shall be well mixed in a composite sample and the sample for test obtained by the quartering method.

7. (*a*) Where it is not practical to visit the plant, samples for both quality and size shall be taken from different parts of the car or boat during unloading. It is recommended that separate samples be taken from the top, middle and bottom of car or boat. These separate samples shall be well mixed in a composite sample and the sample for test obtained by the quartering method. The results of tests on crushed stone for quality are not considered comparable with results from samples specially broken for test in the laboratory, but the general quality of the stone can be ascertained and check tests on various shipments should indicate any change in quality. In this case, tests for both quality and size can be made on the same sample.

(*b*) Where test is to be made for size only, it is recommended that a small set of screens and a pair of scales or some unit measure receptacle for measuring volume be used for field testing in order not to delay decision on the use of the material. Occasional check tests can be obtained from the laboratory to assure a fair degree of accuracy in field testing.

8. (*a*) The sample of crushed stone for mechanical analysis shall weigh at least 50 times the weight of the largest piece therein.

(*b*) The sample for concrete test will depend on the kind of tests to be made and the number of specimens necessary.

C. Sampling of Field Stone and Boulders.

9. A detailed inspection of the deposits of field stone and boulders, over the area where the supply is to be obtained, shall be made. The different kinds of stone and its state of preservation in the various deposits shall be recorded.

10. Separate samples shall be taken of all stone of different classes that a visual inspection indicates, from state of preservation and degrees of lamination, would be considered for use in construction.

11. Records accompanying samples of field stone and boulders, in addition to general information, shall contain the following:

(*a*) Location of supply;

The plotting of the field stone and boulder area on a U. S. topographic or a similar map is recommended for this purpose.

(*b*) Approximate quantity available;

A fairly accurate estimate of amount of stone in fences can be made by measuring a cross-section and pacing the length. It is more difficult to estimate the amount of stone scattered on the ground and ordinarily such deposits do not pay to work unless quite congested.

(*c*) Information regarding the percentage of different classes of stone which were sampled and the percentages of material which can be rejected by visual examination and may have to be handled and spoiled.

This information regarding the percentages of different kinds of material can only be estimated and the degree of accuracy attained will depend almost entirely upon the experience and skill of the individual.

II. Sampling of Blast-Furnace Slag

12. It is recommended that blast-furnace slag be sampled for size and quality by the method specified for broken stone.

III. Sampling of Sand and Gravel

A. Non-Commercial Deposits.

13. Non-commercial as used here includes all undeveloped sand and gravel deposits and all developed deposits where the material is not washed or screened.

14. (*a*) The investigator should realize that few if any natural sand and gravel deposits are uniform, and when a sample is taken the quantity of material in the deposit similar to the sample shall be ascertained as nearly as possible.

(*b*) Where possible, samples of sand shall be taken when it is in a damp condition.

(*c*) If the deposit is worked as a bank or pit and has an open face, the sample shall be taken by channeling the open face so as to respresent material that visual inspection indicates could be used. Care shall be taken to eliminate any overburden or stripping at the top or any that has fallen along the face from the top. It is necessary, especially in small deposits, to excavate test pits some distance back of and parallel to the face to determine the extent of the supply. The number and depth of these pits depend on the quantity of material that is to be taken from the deposit. Separate samples shall be taken from the face of the bank and from test pits. These shall be well mixed in a composite sample and the sample for test obtained by the quartering method.

(*d*) Deposits that have no open face shall be sampled by means of test pits. The number and depth of these will depend on local conditions and the amount of material to be used from the source. A separate sample shall be taken from each pit and where visual examination indicates no radical difference in size of grain, color, etc., these shall be well mixed in a composite sample and the sample for test obtained by the quartering method. Where visual inspection indicates a distinct difference in material from different pits, separate samples shall be taken for test.

(*e*) It is suggested that the colorimetric test be used for determining the percentage of organic material.[1]

15. In addition to the general information accompanying all samples from sand and gravel deposits not commercial sources, the same detailed information shall be supplied as with samples of stone taken from local ledges.

B. Commercial Sand and Gravel Plants.

16. Samples of both sand and gravel from commercial screening or washing plants shall be taken from the bins or storage piles preferably while the material is being loaded from these supplies. The sand and gravel shall be sampled as separate units and shipped as such. It is difficult to secure a representative sample from stock piles and bins and, if conditions require

[1] For a description of this test, see the Standard Method of Test for Organic Impurities in Sands for Concrete (Serial Designation: C 40) of the American Society for Testing Materials on page 27.

sampling from these sources, the following is recommended: Separate samples shall be taken from different parts of the stock pile, care being taken to avoid sampling a segregated area of coarse-grained material which is likely to exist at the base of the pile. In sampling from a bin, separate samples shall be taken from the top and the loading chute. At the latter place at least ½ cu. yd. of material shall be run off and representative samples taken from it. These separate samples shall be well mixed in a composite sample and the sample for test obtained by the quartering method.

17. The size of sand and gravel will be affected by the same factors as broken stone and the same inspection is necessary. In addition, the relative amount of water used in screening must be taken into consideration. The same procedure for taking a sample of broken stone for size is recommended for sampling sand and gravel for size, both at plant and at delivery.

18. Where it is not practical to visit the plant, samples for both quality and size shall be taken from different parts of the car or boat during unloading. It is recommended that separate samples be taken from the top, middle and bottom of car or boat. These separate samples shall be well mixed in a composite sample and the sample for test obtained by the quartering method.

C. Quantity of Sand and Gravel Samples.

19. Samples of run of bank (where the sand and gravel are combined) shall consist of at least 100 lb. of material where the gravel content is 50 per cent or more of the whole. If the gravel is less in percentage, the sample shall be increased in proportion. For example, where the gravel percentage is 25 per cent of the whole the sample should contain 200 lb.

20. Samples of sand shall contain at least 20 lb. of material.

21. Samples of gravel shall contain at least 50 lb. of material.

22. The sample for concrete test will depend on the kind of tests to be made and the number of specimens necessary.

IV. Sampling of Miscellaneous Materials

23. Samples of slag sand, screenings, mine tailings, and all other materials used as a substitute for sand and gravel or broken stone, shall be inspected in the same manner and samples taken in the same way as the materials for which they are substituted.

V. Sampling of Stone Block

24. Samples shall be taken either at the quarry or from cars or boats as directed by the Engineer. They shall be representative of the block which it is proposed to use and no sample shall include blocks that would be rejected by visual inspection.

25. The sample shall consist of at least six blocks and the bedding plane shall be marked on at least two of these.

VI. General Directions for Shipping and Marking Samples

26. Samples of ledge stone, crushed stone and slag shall be shipped in a secure box or bag.

27. Samples of stone block shall be securely crated.

28. Samples of run of bank gravel, sand screenings, and other fine material shall be shipped in a tight box or closely woven bag so there shall be no loss of the finer particles.

29. Each sample or separate container shall be accompanied by a card or regular form, preferably in the container, giving the following information: By whom taken, official title or rank of the sampler; by whom submitted; source of supply; proposed use for the material; and in case of commercial supplies, daily production; geographic location, shipping facilities (name of railroad, canal or river, or other common carrier); and price of the material.

Standard Method of Test for Organic Impurities in Sands for Concrete

Serial Designation: C 40-22

1. The test herein specified is an approximate test for the presence of injurious organic compounds in natural sands for cement mortar or concrete. The principal value of the test is in furnishing a warning that further tests of the sand are necessary before they be used in concrete. Sands which produce a color in the sodium hydroxide solution darker than the standard color should be subjected to strength tests in mortar or concrete before use.

2. (*a*) A representative test sample of sand of about 1 lb. shall be obtained by quartering or by the use of a sampler.

(*b*) A 12 oz. graduated glass prescription bottle shall be filled to the 4½-oz. mark with the sand to be tested.

(*c*) A 3 per cent solution of sodium hydroxide (NaOH) in water shall be added until the volume of sand and liquid after shaking gives a total value of 7 liquid ounces.

(*d*) The bottle shall be stoppered and shaken thoroughly and then allowed to stand for 24 hours.

(*e*) A standard color solution shall be prepared by adding 2.5 cc. of a 2 per cent solution of tannic acid in 10 per cent alcohol to 97.5 cc. of a 3 per cent sodium hydroxide solution. This shall be placed in a 12-oz. prescription bottle, stoppered and allowed to stand for 24 hours.

(*f*) The color of the clear liquid above the sand shall be compared with the standard color solution prepared as in paragraph (*e*) or with a glass of color similar to the standard solution.

3. Solutions darker in color than the standard color have a "color value" higher than 250 parts per million in terms of tannic acid.

Standard Method of Test for Quantity of Clay and Silt in Gravel for Highway Construction

Serial Designation: D 72-21

1. This test covers the determination of the quantity of clay and silt in natural gravel[1] to be used in highway construction.

2. The sample as received shall be moistened and thoroughly mixed, then dried to constant weight at a temperature between 100 and 110° C. (212 and 230° F.).

3. The pan or vessel to be used in the determination shall be 12 in. (30.5 cm.) in diameter by not less than 4 in. (10.2 cm.) deep, as nearly as may be obtained.

4. (*a*) A representative portion of the dry material weighing not less than 50 times the weight of the largest stone in the sample shall be selected from the sample and placed in the pan which has been dried and accurately weighed.

(*b*) Sufficient water shall be poured into the pan to cover the gravel. The gravel shall be agitated vigorously for 15 seconds with a trowel or stirring rod. After it has settled for 15 seconds the water shall be poured off into a tared evaporating dish, care being taken not to pour off any gravel. This is repeated until the wash water is clear. The washed material shall be dried to constant weight in an oven at a temperature between 100 and 110° C. (212 and 230° F.), weighed, and the net weight of gravel determined.

5. The percentage of clay and silt shall be calculated from the formula:

$$\text{Percentage of clay and silt} = \frac{\text{Original wt.—wt. after washing}}{\text{Original wt.}} \times 100.$$

6. For a check on the results, the wash water shall be evaporated to dryness and the residue weighed:

$$\text{Percentage of Clay and Silt} = \frac{\text{Weight of residue}}{\text{Original weight}} \times 100.$$

Tentative Method of Decantation Test for Sand and Other Fine Aggregates

Serial Designation: D 136-22 T

1. This method of test covers the determination of the total quantity of silt, loam, clay, etc., in sand and other fine aggregates.[2]

2. The pan or vessel to be used in the determination shall be approximately 9 in. (230 mm.) in diameter and not less than 4 in. (102 mm.) in depth.

3. The sample must contain sufficient moisture to prevent segregation and shall be thoroughly mixed. A representative portion of the sample sufficient to yield approximately 500 g. of dried material shall then be dried to a constant weight at a temperature not exceeding 110° C. (230° F.).

4. The dried material shall be placed in the pan and sufficient water added to cover the sample (about 225 cc.). The contents

[1] A mixture of sand and pebbles. This test should not be made on coarse aggregate.

[2] This determination of the percentage of silt, clay, loam, etc., will include all water-soluble material present, the percentage of which may be determined separately if desired.

of the pan shall be agitated vigorously for 15 seconds, and then be allowed to settle for 15 seconds, after which the water shall be poured off, care being taken not to pour off any sand. This operation shall be repeated until the wash water is clear. As a precaution, the wash water shall be poured through a 200-mesh sieve and any material retained thereon returned to the washed sample. The washed sand shall be dried to a constant weight at a temperature not exceeding 110° C. (230° F.) and weighed.

5. The results shall be calculated from the formula:

$$\text{Percentage of silt, clay, loam, etc.} = \frac{\text{Original dry wt.—wt. after washing}}{\text{Original dry wt.}} \times 100.$$

6. When check determinations are desired, the wash water shall be evaporated to dryness, the residue weighed, and the percentage calculated from the formula:

$$\text{Percentage of silt, loam, clay, etc.} = \frac{\text{Weight of residue}}{\text{Original dry weight}} \times 100.$$

Standard Method of Test for Unit Weight of Aggregate for Concrete

Serial Designation: C 29-21

This method was approved May 29, 1923, as "Tentative American Standard" by the American Engineering Standards Committee

1. The unit weight of fine, coarse, or mixed aggregates for concrete shall be determined by the following method:

2. (*a*) The apparatus required consists of a cylindrical metal measure, a tamping rod, and a scale or balance, sensitive to 0.5 per cent of the weight of the sample to be weighed.

(*b*) *Measures.*—The measure shall be of metal, preferably machined to accurate dimensions on the inside, cylindrical in form, water-tight, and of sufficient rigidity to retain its form under rough usage, with top and bottom true and even, and preferably provided with handles.

The measure shall be of 1/10, ½ or 1-cu. ft. capacity, depending on the maximum diameter of the coarsest particles in the aggregate, and shall be of the following dimensions:

Capacity cu. ft.	Inside Diameter, in.	Inside Height, in.	Minimum Thickness of Metal, U. S. Gage	Diameter of Largest Particles of Aggregate, in.
1/10	6.00	6.10	No. 11	Under ½
½	10.00	11.00	No. 8	Under 1½
1	14.00	11.23	No. 5	Over 1½

(*c*) *Tamping Rod.*—The tamping rod shall be a straight metal rod ¾ in. in diameter and 18 in. long, with one end tapered for a distance of 1 in. to a blunt bullet-shape point.

3. The measure shall be calibrated by accurately determining the weight of water at 16.7° C. (62° F.) required to fill it. The factor for any unit shall be obtained by dividing the unit weight of water at 16.7° C. (62° F.)[1] by the weight of water at 16.7° C. (62° F.) required to fill the measure.

4. The sample of aggregate shall be room dry and thoroughly mixed.

5. (*a*) The measure shall be filled one-third full and the top levelled off with the fingers. The mass shall be tamped with the pointed end of the tamping rod twenty-five times, evenly distributed over the surface. The measure shall be filled two-thirds full and again tamped twenty-five times as before. The measure shall then be filled to overflowing, tamped twenty-five times, and the surplus aggregate struck off, using the tamping rod as a straight edge.

In tamping the first layer the rod should not be permitted to forcibly strike the bottom of the measure. In tamping the second and final layers, only enough force to cause the tamping rod to penetrate the last layer of aggregate placed in the measure should be used. No effort should be made to fill holes left by the rod when the aggregate is damp

(*b*) The net weight of the aggregate in the measure shall be determined. The unit weight of the aggregate shall then be obtained by multiplying the net weight of the aggregate by the factor found as described in Section 3.

6. Results with the same sample should check within 1 per cent.

[1] The unit weight of water at 16.7° C. (62° F.) is 62.355 lb. per cu. ft.

Standard Method of Test for Sieve Analysis of Aggregates for Concrete

Serial Designation: C 41-24

1. A representative test sample of the aggregate shall be selected by quartering or by use of a sampler, which after drying will give not less than the following:

(*a*) Fine aggregate, 500 g.

(*b*) Coarse aggregate or a mixture of fine and coarse aggregates, weight in grams, 3000 times size of largest sieve required, measured in inches.

TABLE I

Sieve No.[2] or Size in inches	Sieve Opening		Wire Diameter		Tolerance, per cent			
					Average Opening	Wire Diameter		Maximum Opening
	mm.	in.	mm.	in.		Under	Over	
No. 100	0.149	0.0059	0.102	0.0040	6	15	35	40
No. 50	0.297	0.0117	0.188	0.0074	6	15	35	40
No. 30	0.59	0.0232	0.33	0.0130	5	15	30	25
No. 16	1.19	0.0469	0.54	0.0213	3	15	30	10
No. 8	2.38	0.0937	0.84	0.0331	3	15	30	10
No. 4	4.76	0.187	1.27	0.050	3	15	30	10
⅜-in.	9.5	0.375	2.33	0.092	3	10	10	10
¾-in.	19.0	0.75	3.42	0.135	3	10	10	10
1-in.	25.4	1.00	4.12	0.162	3	10	10	10
1½-in.	38.0	1.50	4.50	0.177	3	10	10	10
2-in.	50.8	2.00	4.88	0.192	3	10	10	10
3-in.	76.0	3.00	6.3	0.25	3	10	10	10

2. The sample shall be dried at not over 110° C. (230° F.) to constant weight.

3. (*a*) The sieves shall be of square-mesh wire-cloth and shall be mounted on substantial frames constructed in a manner that will prevent loss of material during sifting.

(*b*) The size of wire and sieve openings shall be as given in Table I.

4. (*a*) The sample shall be separated into a series of sizes by means of the sieves specified in Section 3. Sifting shall be continued until not more than 1 per cent by weight of the sample passes any sieve during 1 minute.

(*b*) Each size shall be weighed on a balance or scale which is sensitive to 1/1000 of the weight of the test sample.

(*c*) The percentage by weight of the total sample which is finer *than each* of the sieves shall be computed.

5. (*a*) The percentages in sieve analysis shall be reported to the nearest whole number.

(*b*) If more than 15 per cent of a fine aggregate is coarser than the No. 4 sieve, or more than 15 per cent of a coarse aggregate is finer than the No. 4 sieve, the sieve analysis of the portions finer and coarser than this sieve shall be reported separately.

Tentative Method of Test for Consistency of Portland-Cement Concrete

Serial Designation: D 138-25 T

1. This test covers the method to be used both in the laboratory and in the field for determining consistency of concrete.[3]

2. The test specimen shall be formed in a mold of No. 16 gage galvanized metal in the form of the lateral surface of the frustrum of a cone with the base 8 in. in diameter, the upper surface 4 in. in diameter, and the altitude 12 in. The base and the top shall be open and parallel to each other and at right angles to the axis of the cone. The mold shall be provided with foot pieces and handles as shown in Fig. 1.

[2] The requirements for sieves No. 100 to No. 4 conform to the requirements of the U. S. Standard Sieve Series as given in U. S. Bureau of Standards *Letter Circular No. 74.* The liberal tolerances will permit the use of certain sieves which do not exactly correspond to the numbers given in table.

[3] This test is not considered applicable when there is a considerable amount of coarse aggregate over 2 in. in size in the concrete. The committee is now working on a method suitable for determining the consistency of concrete using aggregate over 2 in. in size.

3. When the test is made at the mixer, the sample shall be taken from the pile of concrete immediately after the entire batch has been discharged. When testing concrete that has been hauled from a central mixing plant, the sample shall be taken from the concrete immediately after it has been dumped on the subgrade.

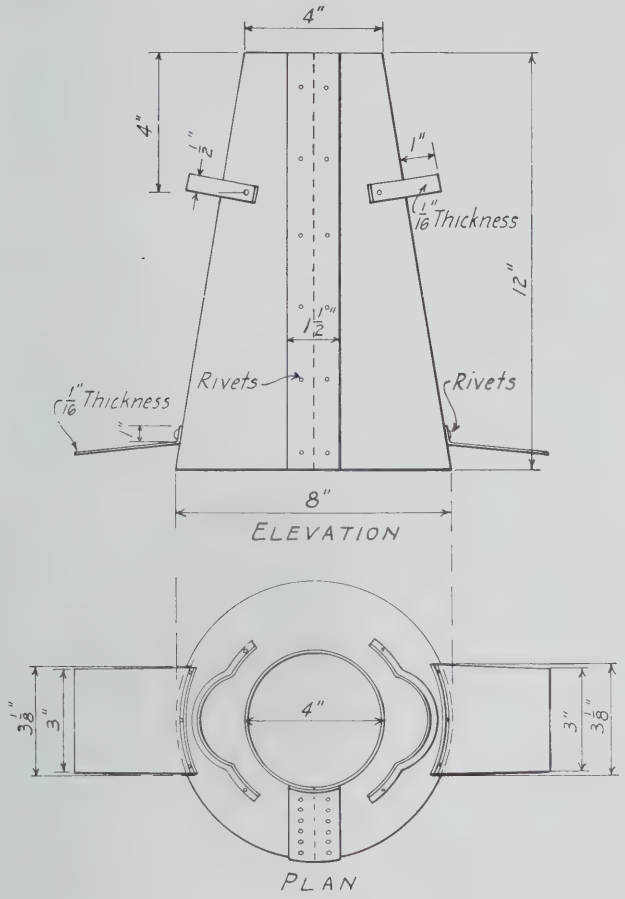

Fig. 1

4. The mold shall be placed on a flat, non-absorbent surface, such as a smooth plank or a slab of concrete, and the operator shall hold the form firmly in place, while it is being filled, by standing on the foot pieces. The mold shall be filled to about one-fourth of its height with the concrete which shall then be puddled, using 20 to 30 strokes of a ½-in. rod pointed at the lower end. The filling shall be completed in successive layers similar to the first and the top struck off so that the mold is exactly filled. The mold shall then be removed by being raised vertically, immediately after being filled. The molded concrete shall then be allowed to subside until quiescent and the height of the specimen measured.

5. The consistency shall be recorded in terms of inches of subsidence of the specimen during the test, which shall be known as the slump.

Slump = 12 − inches of height after subsidence

Standard Method of Making and Storing Specimens of Concrete in the Field

Serial Designation: C 31-21

1. The methods herein specified apply to molding and storing of test specimens of concrete sampled from concrete being used in construction.

2. The test specimens shall be cylindrical in form with the length twice the diameter. In general a mold whose diameter is not less than four times the diameter of the largest size aggregate shall be used. (The sizes most commonly used are 6 by 12-in. and 8 by 16-in. cylinders.)

3. (*a*) The molds shall be cylindrical in form, made of non-absorbent material, and shall be substantial enough to hold their form during the molding of the test specimens. They shall not vary in diameter more than $\frac{1}{16}$ in. in any direction, nor shall they vary in height more than $\frac{1}{16}$ in. from the height required. They shall be substantially water-tight so that there will be no leakage of water from the test specimen during molding.

(*b*) Each mold shall be provided with a base plate having a plane surface and made of non-absorbent material. This plate shall be large enough in diameter to properly support the form without leakage. Plate glass or planed metal are satisfactory for this purpose. A similar plate should be provided for covering the top surface of the test specimen after being molded.

(*c*) Suggestions for suitable forms are shown in Figs. 1, 2 and 3. (Fig. 2 omitted from this text.)

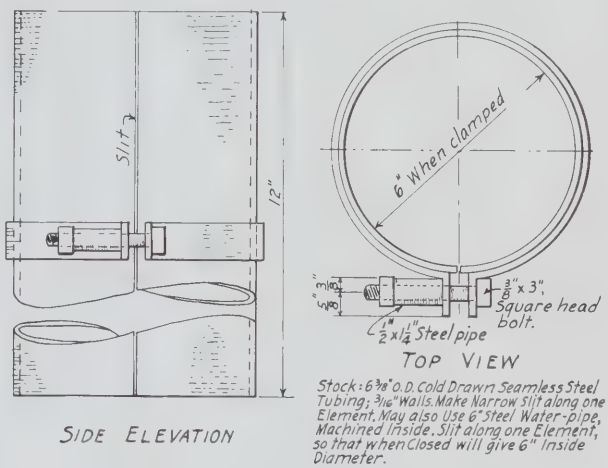
Slit
12"
SIDE ELEVATION
6" When clamped
5 3/8"
3/8" x 3", Square head bolt.
1/2" x 1 1/4" Steel pipe
TOP VIEW
Stock: 6 3/8" O.D. Cold Drawn Seamless Steel Tubing; 3/16" Walls. Make Narrow Slit along one Element. May also Use 6" Steel Water-pipe, Machined Inside. Slit along one Element, so that when Closed will give 6" Inside Diameter.

Fig. 1

4. (*a*) Concrete for the test specimens shall be taken immediately after it has been placed in the work. All the concrete for each sample shall be taken from one place. A sufficient number of samples—each large enough to make one test specimen—shall be taken at different points so that the test specimens made from them will give a fair average of the concrete placed in that portion of the structure selected for tests. The location from which each sample is taken shall be noted clearly for future reference.

(*b*) In securing samples, the concrete shall be taken from the mass by a shovel or similar implement and placed in a large pail or other receptacle for transporting to the point of molding. Care shall be taken to see that each test specimen represents the total mixture of the concrete in that place. Different samples shall not be mixed together but each sample shall make one specimen.

5. (*a*) The pails or other receptacles containing the samples of concrete shall be taken as quickly as possible to the place selected for molding test specimens. To offset segregation of the concrete occurring during transportation, each sample shall be dumped into a non-absorbent water-tight receptacle and, after slight stirring, immediately placed in the mold.

(*b*) The test specimens shall be molded by placing the concrete in the form in layers approximately 4 in. in thickness. Each layer shall be puddled with 25 to 30 strokes with a ⅝ to ¾-in. bar about 2 ft. long, tapered slightly at the lower end. After puddling the top layer, the surface concrete shall be struck off with a trowel and covered with the top cover plate which will later be used in capping the test specimens.

6. Two to four hours after molding, the test specimens shall be capped with a thin layer of stiff neat cement paste in order that the cylinder may present a smooth end for testing. The cap can best be formed by means of a piece of plate glass ¼ in. thick and of a diameter 2 or 3 in. larger than that of the mold. This plate is worked on the fresh cement paste until it rests on top of the form. The cement for capping should be mixed to a stiff paste some time before it is to be used in order to avoid the tendency of the cap to shrink. Adhesion of the concrete to the top and bottom plates can be avoided by oiling the plates or by inserting a sheet of paraffined tissue paper.

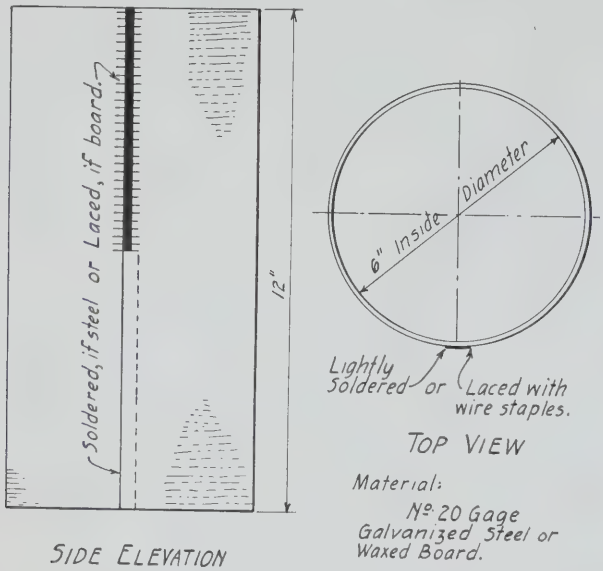

Fig. 3

7. At the end of 48 hours the test specimens shall be removed from the molds and buried in damp sand except in case the molds shown in Fig. 3 are used; in this case test specimens may be buried in damp sand without removal of the mold, thus permitting shipping of the test specimens in the molds.

8. (*a*) The test specimens shall remain buried in damp sand until 10 days prior to the date of test. They shall then be well packed in damp sand or wet shavings and shipped to the testing laboratory, where they shall be stored either in a moist room or in damp sand until the date of test.

(*b*) Should a 7-day test be required, the test specimens shall remain at the works as long as possible to harden and then shall be shipped so as to arrive at the laboratory in time to make the test on the required date.

Standard Methods of Making Compression Tests of Concrete

Serial Designation: C 39-25

1. These methods are intended to cover compression tests of concrete made in a laboratory where accurate control of quantities of materials and test conditions is possible. They are designed to apply primarily to hand-mixed concrete. These methods may be used with slight modification in making tests of concrete for wearing resistance, bond between concrete and steel, impermeability, etc. The investigation of machine-mixed concrete will require certain obvious changes in the method. For methods of conducting compression tests of concrete specimens made during the progress of construction work, see the Standard Methods of Making and Storing Specimens of Concrete in the Field (Serial Designation: C31-21 of the American Society for Testing Materials.

2. Materials shall be brought to room temperatures (65 to 75° F.) before beginning tests. Cement shall be stored in a dry place; preferably in covered metal cans. The cement shall be thoroughly mixed in advance, in order that the sample may be uniform throughout the tests. It shall be sifted through a No. 16 sieve and all lumps rejected. Aggregates shall be in a room-dry condition when used in concrete tests. In general, aggregates should be separated on the No. 4, ⅜-in. and 1½-in. sieves and recombined to the average original sieve analysis for each batch. Fine aggregate should be separated into different sizes also in cases where unusual gradings are being studied.

3. Representative samples of all concrete materials shall be secured for preliminary tests prior to the proportioning and mixing of the concrete. Cement test samples may be made up of a small quantity from each sack used in the concrete tests. Test samples of aggregates may be taken from larger lots by quartering.

4. Cement shall be subjected to test, using the methods described in the Standard Specifications and Tests for Portland Cement (Serial Designation: C9-26) of the American Society for Testing Materials.

5. Fine aggregates (passing through a No. 4 sieve) shall be subjected, when required, to the following tests:

(*a*) Sieve analysis test made in accordance with the Standard Method of Test for Sieve Analysis of Aggregates for Concrete (Serial Designation: C41-24) of the American Society for Testing Materials.

(*b*) Test for organic impurities (natural sand only) made in accordance with the Standard Method of Test for Organic Impurities in Sands for Concrete (Serial Designation: C40-22) of the American Society for Testing Materials.

(*c*) Test for quantity of silt, clay or dust made in accordance with the Tentative Method of Decantation Test for Sand and Other Fine Aggregates (Serial Designation: D 136-22 T) of the American Society for Testing Materials.

(*d*) Test for unit weight made in accordance with the Standard Method of Test for Unit Weight of Aggregate for Concrete Serial Designation: C29-21) of the American Society for Testing Materials.

(*e*) Strength test of 1:3 mortar by weight at 7 and 28 days in comparison with standard sand mortar.

6. Coarse aggregates (retained on a No. 4 sieve) shall be subjected when required to the following tests:

(*a*) Sieve analysis test as specified under Section 5 (*a*);

(*b*) Test for quantity of silt, clay or dust, as specified under Section 5 (*c*);

(*c*) Test for unit weight as specified under Section 5 (*d*).

7. The unit weight of mixed fine and coarse aggregates as used in concrete tests shall be determined in accordance with the method specified in Section 5 (*d*).

8. The quantities of each size of aggregate to be used in each batch shall be determined on the basis of the sieve analysis and the unit weight of the mixed aggregate. The exact quantities of cement and of each size of aggregate for each batch shall be determined by weight. The quantity of water for each batch shall be accurately measured. The quantities of materials may be expressed as (*a*) 1 volume of cement to—volumes of total aggregate mixed as used, or (*b*) 1 volume of cement,—volumes fine aggregate, and—volumes of coarse aggregate.

NOTE—It is impracticable to give a general method for proportioning concrete for experimental purposes; the details will necessarily vary widely with the purpose for which the tests are made. The following procedure is suggested for specific cases:

(*a*) Vary the cement content by 10 per cent intervals above and below assumed quantity.

(*b*) Vary the proportions of fine to coarse aggregate, measured separately, at intervals of 10 per cent.

(*c*) Vary the quantity of mixing water by intervals of 10 per cent.

9. Compression tests of concrete shall be made on cylinders of a diameter equal to one-half the length. The standard shall be 6 by 12-in. cylinders where the coarse aggregate does not exceed 2 in. in size; for aggregates larger than 2 in., 8 by 16-in. cylinders shall be used; 2 by 4-in. cylinders may be used for mixtures without coarse aggregate.

10. (*a*) Concrete shall be mixed by hand in batches of such size as to leave a small quantity of concrete after molding a single test piece. The batch shall preferably be mixed in a shallow galvanized steel pan with a 10-in. bricklayer's trowel which has been blunted by cutting off about 2½ inches of the point, as follows:

(*b*) The cement and fine aggregate shall be mixed dry until the mixture is homogeneous in color;

(*c*) The coarse aggregate shall be added and mixed dry;

(*d*) Sufficient water shall be added to produce concrete of the required workability;

NOTE—Concrete tests should be made on *plastic* mixtures. It is of the utmost importance that a uniform degree of workability be secured in tests involving comparisons of different materials and methods.

(*e*) The whole shall be mixed thoroughly until the entire mass is homogeneous in appearance.

11. The workability or plasticity of each batch of concrete shall be measured immediately after mixing by one of the following methods:

(*a*) Slump test made in accordance with the Tentative Method of Test for Consistency of Portland Cement Concrete (Serial Designation: D 138-25 T) of the American Society for Testing Materials.

(*b*) Flow test made by placing a metal form in the shape of a frustrum of a cone 6¾ in. in top diameter, 10 in. in bottom diameter, 5 in. deep, on the table of the flow apparatus.[1] The fresh concrete shall be placed in the mold in two layers. Each layer shall be puddled and finished as described in Section 13. Immediately after molding, the form shall be removed by a steady upward pull; the specimen raised ½ in. and dropped 15 times in about 6 seconds by means of a suitable cam and crank. The spread of the fresh concrete due to this treatment as compared with the original bottom diameter of the cone, expressed as a percentage, is the "flow."

12. The forms shall preferably be of metal. Each form shall be provided with a machined metal base plate, and shall be oiled with a heavy mineral oil before using. Particular care shall be taken to obtain tight forms so that the mixing water will not escape during molding.

NOTE—The best type of form consists of lengths of cold-drawn steel tubing, split along one element and closed by means of a circumferential band and bolt. Satisfactory forms can be made from lengths of steel water-pipe machined on the inside, from rolled metal plates, from galvanized steel, machined iron or steel castings. Paraffined cardboard molds will give good results under expert supervision.

13. Concrete test pieces shall be molded by placing the fresh concrete in the form in layers 3 to 4 in. in thickness. Each layer shall be puddled with 25 strokes with a ⅝-in. round steel bar of a length 9 in. greater than the length of the mold, pointed at the lower end. After the top layer has been puddled, the surplus concrete shall be cleaned off with a trowel, and the mold covered with a machined metal plate or a piece of plate glass at least ¼ in. thick, which will be used later in capping the test piece.

14. Two to four hours after molding, the test pieces shall be capped with a thin layer of stiff neat cement paste in order that the cylinders may present a smooth end for loading. The cap shall be formed by means of a machined metal plate or a piece of plate glass of suitable size, at least ¼ in. thick, worked down on the fresh cement paste until it rests on the top of the cylinder form. The cement for capping shall be mixed to a stiff paste before beginning to mix the concrete; in this way the tendency of the cap to shrink will be largely eliminated. The adhesion of the concrete to the metal base plate and the glass can be largely eliminated by oiling the cover plate and by inserting a sheet of paraffined tissue paper.

15. Concrete test pieces shall be removed from the forms 20 to 48 hours after molding, marked, weighed and stored in damp sand, under damp cloths or in a moist chamber until the date of test. The temperature of the curing room should not fall outside the range of 60 to 75° F.

16. Tests shall be made at the age of 7 and 28 days; ages of 3 months and 1 year are recommended, if longer-time tests are required.

17. Three to five test pieces should be made on different days in investigations in which accurate comparisons are desired.

18. Compression tests shall be made immediately upon removal of the concrete test pieces from the curing room; that is, the test pieces shall be loaded in a damp condition. The length and average diameter of the test pieces shall be measured in inches and hundredths; two diameters shall be measured at right angles near the mid-length. The test piece shall be weighed immediately before testing.

19. In general, only the ultimate compressive strength of the cylinders need be observed. The metal bearing plates of the testing machine shall be placed in contact with the ends of the test piece; cushioning materials shall not be used. An adjustable bearing block shall be used to transmit the load to the test piece. The bearing block shall be placed on *top* of the test piece in vertical testing machines. The diameter of the bearing block shall be approximately the same as that of the test piece. The upper section of the bearing block shall be kept in motion as the head of the testing machine is brought to a bearing on the test piece.

20. The load shall be applied uniformly and without shock. The moving head of the testing machine should travel at the rate of about 0.05 in. per minute when the machine is running idle.

21. The total load indicated by the testing machine at failure of the test piece shall be recorded and the unit compressive strength calculated in pounds per square inch, the area computed from the average diameter of the cylinder being used. The type of failure and appearance of the concrete shall be noted.

22. The weight of the concrete in pounds per cubic foot shall be determined from the weight of the specimens and their dimensions.

23. Density and yield of concrete when required shall be calculated from the unit volumes of the constituent materials and the volume of the concrete. Density is here understood to be the ratio of solids in the concrete to the total volume of the mass. Yield is the volume of concrete resulting from one volume of aggregate mixed as used.

24. The report of tests shall include the following:

(*a*) The kind and origin of concrete materials;

(*b*) Complete data on all tests of cement and aggregates;

(*c*) A description of methods of making and testing the concrete, where methods deviate from the proposed standards;

(*d*) The quantities of cement, aggregates and water in each batch;

(*e*) The method of measuring workability or plasticity with "slump" or "flow" of concrete;

(*f*) The quantity of water expressed as a ratio to volume of cement;

(*g*) The age at test;

(*h*) The size of test pieces;

(*i*) The date of molding and testing each cylinder;

(*j*) The compressive strength in pounds per square inch of each test piece and average of tests in a set;

(*k*) A description of failure and appearance of concrete on each test piece;

(*l*) The unit weight, density and yield of the concrete.

Sedimentation Test for Approximate Quantity of Clay and Silt in Sand

This test is not an A. S. T. M. Standard.

A test that is often used in the field is the sedimentation test which shows the approximate quantity of clay and silt in sand. This test is made as follows:

A 32-ounce, graduated prescription bottle is filled to the 14-ounce mark with sand and clear water added to the 28-ounce mark. This mixture is then shaken vigorously and the contents allowed to settle for one hour. If more than 1 ounce of sediment then appears above the aggregate the sand should be rejected. The sand may be subjected to washing and samples again tested and the sand approved for use if the test requirements are fulfilled.

[1] For a description and illustration of one design for a flow-table, see *Proceedings*, Am. Soc. Test. Mats., Vol. XX, Part II, p. 242 (1920), and "Concrete," June, 1920, p. 274.

A FEW EXAMPLES OF FIELD CONTROL

The subject of field tests for controlling the quality of concrete has aroused considerable interest and each year some method of control is used on a larger number of projects. A few examples are listed below. Full descriptions will be found in the references given.

ONTARIO-NIAGARA POWER DEVELOPMENT STRUCTURES. *Engineering News-Record*, April 13, 1922. Four classes of concrete having strengths of 1000, 1500, 2000 and 2500 lb. per sq. in. total 410,000 cu. yd. of concrete. Water controlled giving satisfactory results.

JAMAICA BAY VIADUCT, New York, N. Y. *Engineering News-Record*, February 9, 1922. Concrete exposed to sea water specified strength of 3000 lb. per sq. in. Water controlled by slump. Tests show higher strength than specified.

MIAMI RIVER BRIDGE, Sidney, Ohio. *Engineering News-Record*, October 11, 1923. Concrete designed to give strengths of 2000, 2500 and 3000 lb. per sq. in. Water controlled by slump test.

DELAWARE RIVER BRIDGE, Philadelphia, Pa., Camden, N. J. Proceedings, American Concrete Institute, 1925. Proportions fixed from sieve analyses. Water content controlled by slump test. Design tables permitted quick adjustment of mix after each sieve analysis.

BECK'S RUN BRIDGE, Pittsburgh, Pa. Proceedings, American Concrete Institute, 1925. Water measured and checked by slump test. Proportions calculated from fineness modulus. No additional cost.

SIX REINFORCED CONCRETE BUILDINGS in New York City. Proceedings, American Concrete Institute, 1925. Water-cement ratio specification used. Mix calculated by fineness modulus. All strengths tested higher than design.

WACKER DOUBLE-DECKED DRIVE, Chicago, Ill. *Engineering News-Record*, October 22, 1925. Seven gallons water per sack cement specified. Proportions determined by fineness modulus. Inundator employed to eliminate bulking of sand. 1:6 concrete tested 4000 lb. per sq. in.

PORTLAND CEMENT ASSOCIATION BUILDING, Chicago, Ill. Proceedings, American Concrete Institute, 1926. Water-cement ratios specified. Trial method of proportioning used.

SIX REINFORCED CONCRETE BUILDINGS in New York City. Long Island City, Mt. Vernon and Brooklyn, N. Y., and Waterbury, Conn. Proceedings, American Concrete Institute, 1926. Water-cement ratios used. Job curves determined for each project. Proportions determined from fineness modulus.

ALABAMA STATE HIGHWAY, No. 45, Calhoun County. *Concrete Highway Magazine*, February, 1926. Twenty-three miles of concrete road. Central proportioning plant. One sieve analysis per day. Frequent slump tests Cement content of 1.6 bbl. per cu. yd. of concrete produced 4300 lb. average strength.

PORTLAND CEMENT ASSOCIATION

A National Organization to Improve and Extend the Uses of Concrete

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